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ORIGINAL ARTICLE

Experimental investigation of cutting temperature and surface roughness for different cutting fluids during turning of Duplex stainless steel-2205 under minimum quantity lubrication technique

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ABSTRACT – Duplex stainless steel (DSS)-2205 comes under hard to machine material owing to its inherent properties but more applications in severe working conditions hence, selection of turning process parameters and suitable cutting fluids of DSS-2205 is essential. In the present work, investigate the performance of Deionized water, neat cut oil, and emulsified fluid on cutting temperature and surface roughness during turning of duplex stainless steel-2205 under minimum quantity lubrication technique. Based on a face-centered composite design, 20 experiments were conducted with varying speed, feed, and depth of cut in three levels for three different fluids. Analysis of variance (ANOVA) is used to identify significant parameters that affect the response. Numerical optimization was carried out under Desirability Function Analysis (DFA) for cutting temperature during deionized water cutting fluid for surface roughness during emulsified cutting fluid. Depth of cut is the significant factor for cutting temperature contribution is 74.83% during Deionized water as a fluid, and feed is the significant factor for surface roughness contribution is 93.57% during emulsified fluid. The optimum cutting parameters were determined for speed (50m/min), feed (0.051mm/rev) and depth of cut (0.4mm). Experimental results revealed that Deionized water gives better results for reduced the cutting temperature and emulsified fluid for surface roughness reduction.

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INTRODUCTION

Turning is one of the secondary manufacturing processes in which removes the diameter of material with the help of the cutting tool to get the final size and shape of the component. In industrial manufacturing, it is essential to know the turning characteristics of new constructional materials [1]. Duplex stainless steel-2205 is a new steel material. It contains a mixed microstructure of austenite and ferrite. This phase combination produced excellent mechanical properties and high corrosion resistance. Duplex stainless steel-2205 is a verity of industrial applications like piping, vessels, valves, heat exchangers, and fittings [2]. The turning of this material is around 10-20% slower than for other steel alloys due to high strain hardening rate, low thermal conductivity, high toughness, hardness, and heat concentrating on the cutting edges [3]. The turning performance of any material is primarily based on cutting temperature developed, surface roughness, cutting force, and tool wear. These are mainly correlating with turning parameters of speed, feed, depth of cut, and cutting fluids [3, 4]. Philip Selvaraj et al. [5] investigated the influence of cutting speed and feed on the surface roughness during dry turning of nitrogen alloyed duplex stainless steel. The results reveal that the increasing cutting speed decreases the surface roughness until a particular point and then increasing. Thiyagu et al. [6] investigate the cutting force and surface roughness during the dry turning of DSS-2205. The results revealed that feed and speed were the most influential factors for surface roughness, feed, and nose radius for cutting force. Nagraj Patil et al. [7] comparative study on contrast cryogenic treated and untreated carbide cutting tool in turning operation of AISI304 steel to find the effect of parameters on surface roughness and tool wear results revealed that cryogenic treated cutting tools significantly reduction in surface roughness improves resistance to wear than the untreated one. In order to improve the turning performance of hard stainless steel materials, the application and selection of cutting fluids are important [8]. The cutting fluids have reduced the friction among the tool, work, and chips, the heat generated in the machining zone, and acts as a lubricant [9]. In turning difficult to machine steel alloys, water-based, emulsified, and mineral based cutting fluids are preferred [9, 10]. The flood coolant type application is not ecological in machining due to a large amount of cutting fluid are required hence, the Minimal Quantity Lubrication (MQL) has been gaining as an alternative solution [11, 12]. MQL is a technique in which the cutting fluid is broken into small finer particles with the compressed air called aerosol in the system, and this mixture of fluid and air is applied in the cutting zone under high pressure in the form of the jet through nozzle [13]. Sharma et al. [14] made a review on MQL with dry and flood cooling during machining and suggested that MQL is much

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better than other cooling. Vishal S et al. [15] look into the effect of speed, feed, and depth of cut on surface finish and concluded that MQL is better performance also economical than other conditions. K.G Sathisha et al. [16] studied the effect of machining parameters spindle speed, feed, and depth of cut under the dry and wet turning for AISI 1018 steel. The experiment was conducted with dry and two types of cutting fluids, soluble oil and palm oil to find tool tip temperature. Soluble oil gives better results comparing with Palm oil. E. Kuram et al. [17] study the effect of refined sunflower oil and mineral-based oils on thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel. Many researchers are explore the application of cutting fluids with MQL. They concluded that the performance of machining operations can be enhanced, and some of the researchers are suggested that choice and optimization of the parameters are very critical in any operation [18-20]. The majority of them use desirability function analysis (DFA). The DFA is one of the most generally utilized strategies in the industry for the optimization of parameters. Nabil Kribes et al. [21] experimented on 4140 steel under the RSM technique, and the DF approach was used to find optimum parameters in hard turning. Lakhdar B et al. [22] investigation on turning Martensitic stainless steel 420 using RSM and optimum parameters was analyzed under composite desirability function. L. Bouzid et al. [23] investigate the surface roughness and cutting force in finish turning of AISI D3-hardened steel using carbide, ceramic, and coated ceramic inserts. The paper concluded that the desirability functional approach is found to be most appropriate for dealing with multi-response optimization problems. Walid azizi et al. [24] investigate the influence of parameters on 52100 steel in turning and parameter optimization through the DF approach in order to minimize responses.

It is evident from the above literature review the following literature gaps were identified. Very limited investigations were reported on the studies on surface roughness under dry turning but not for cutting temperature. Duplex stainless steel-2205 is having a wide variety of applications but very less literature to learn the effect of parameters under different cutting fluids on the cutting temperature and surface roughness.

In the current work, investigate the performance of DI water, neat cut oil, and emulsified fluid during turning of duplex stainless steel-2205 under MQL to identify significant process parameters affecting the response through ANOVA and optimization of parameters were obtained through the desirability function approach.

EXPERIMETAL DETAILS

Material, Cutting Tool and Cutting Fluids

The experimental investigation is performed on duplex stainless steel-2205 having specifications of 300mm length and 40mm diameter. The machining of duplex stainless steel-2205 is about 10-20% slower than for other steel alloys because, high work hardening rate, low thermal conductivity, high toughness, and hardness around 234BHN. Table 1 shows the chemical composition of the duplex stainless steel-2205. The cutting tool used for turning the experiment was carbide coated insert with ISO specification TNMG 160404 MS PR-1535 Kyocera make with PVD multi-layer coating. The tool-holder for turning is Nice Company made MTJNR 16X16mm Shank size with right-hand side use.

Table 1. Chemical composition of DSS-2205

Typical analysis Avg values%	C	Si	Mn	Cr	Ni	Mo	P	S	Fe
	0.029	0.283	1.630	22.1	4.5	2.95	0.030	0.020	Balance

The cutting fluid during turning plays a very important role to reduce the cutting temperature developed between the tool and workpiece and improve the surface finish of the component. Various base fluids are used as cutting fluids for turning hard stainless steel materials in the industry. In the present work, Deionized water, Neat cut oil, and Emulsified oil (1:20 concentration) with DI water are selected based on a literature survey and properties of the base fluids. Table 2 shows the type of cutting fluids and properties.

Table 2. Cutting fluids type and properties

Base fluids	Density (g/cm^3)	Thermal Conductivity (W/m-K)	Dynamic Viscosity (cP)
De Ionized water	0.995	0.601	1.2
Neat cut oil	0.865	0.144	37
Emulsified oil with DI water (1:20) Concentration	0.996	0.527	1.4

Experimental Conditions

The twenty experiments were conducted with varying speed, feed and depth of cut in three levels for three different cutting fluids to measure output response of cutting temperature and surface roughness. Table 3 shows the levels of experiments and factors.

Table 3. Levels of experiments and factors

Factors	Unit	Notations	Low level (-1)	Medium Level (0)	High Level (1)
Cutting speed	m/min	V_C	50	70	90
Feed	mm/rev	f	0.051	0.128	0.205
Depth of cut	mm	d	0.4	0.8	1.2

Experiment Setup

Turning experiments were carried out using the MAGNUM-1430 precision variable lathe machine at varying speed, feed, and depth of cut for three levels with three different cutting fluids. The response of cutting temperature and surface roughness was measured using a digital thermometer of K type and Taylor Hobson surtronic-S128. The Figure 1 shows the machining setup with minimum quantity lubrication. The response surface design and analysis were performed using Design Expert-12 software.

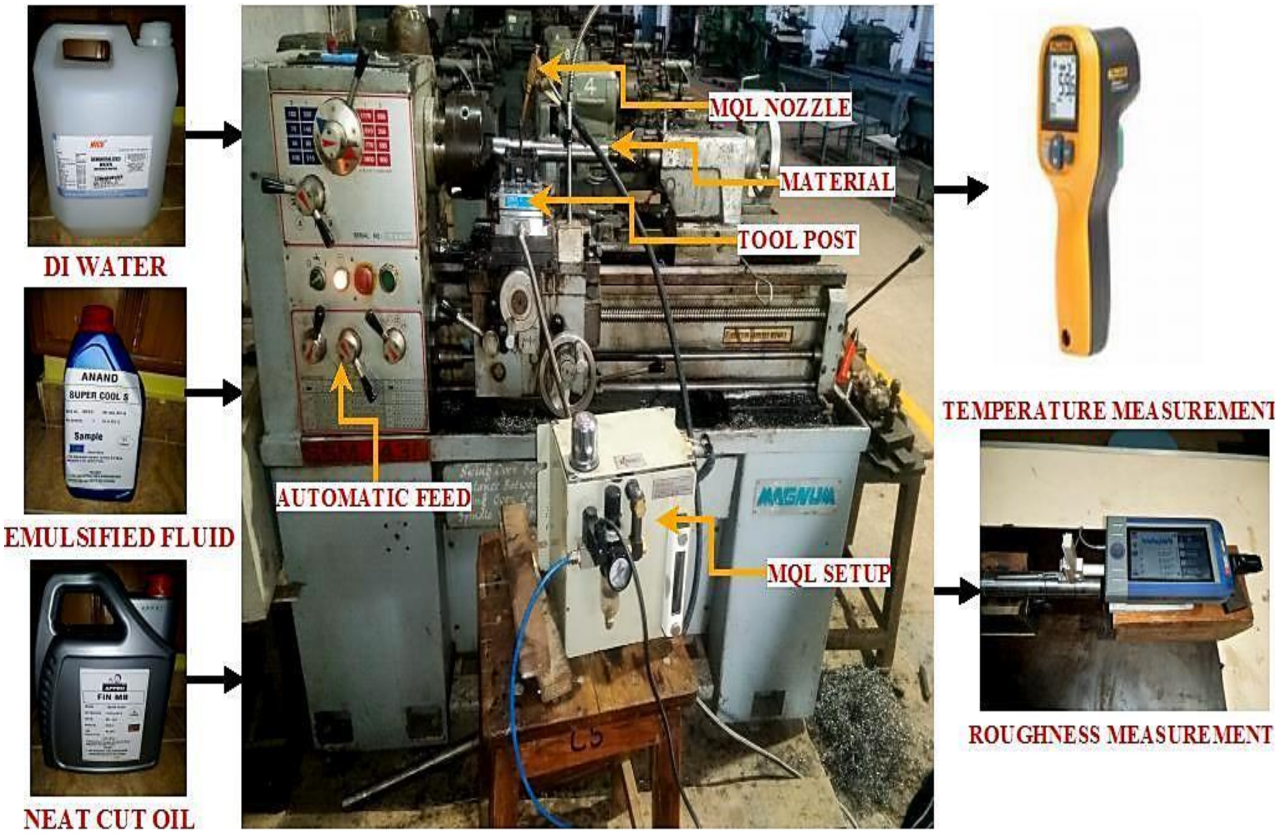


Figure 1. Machining setup with MQL and response measurement

RESULTS

The turning Experiment was carried out based on a face-centered composite (CCF) design for three factors and three levels; the 20 experiments are designed. This consists of 8 fractional factorial points, 6 axial/star points, and 6 center points. Table 4 shows the order of the experiments and experimental results for cutting temperature and surface roughness for different cutting fluids.

Table 4. Experimental results for different cutting fluids

Run No	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cutting Temperature(^{0}C)			Surface Roughness (µm)		
				DI water	Neat Cut oil	Emulsified Fluid	DI water	Neat Cut oil	Emulsified Fluid
1	50	0.051	0.4	32	44	27	1.5	1.13	0.66
2	50	0.051	1.2	63	77	66	2.04	2.3	1.98
3	50	0.205	0.4	52	58	55	3.82	4.10	3.80
4	50	0.205	1.2	58	68	61	4.4	4.42	4.25
5	90	0.051	0.4	52	57	54	1.64	1.72	1.58
6	90	0.051	1.2	78	99	89	1.91	2.14	1.89
7	90	0.205	0.4	49	59	55	3.78	3.89	3.53
8	90	0.205	1.2	79	88	83	4.11	4.22	4.01
9	50	0.131	0.8	62	84	78	2.46	2.5	2.45
10	90	0.131	0.8	78	108	95	2.18	2.25	2.15
11	70	0.051	0.8	64	74	65	1.42	1.5	1.20
12	70	0.205	0.8	69	78	71	3.52	3.75	3.35
13	70	0.131	0.4	58	85	64	2.35	2.42	2.21
14	70	0.131	1.2	72	99	88	2.7	2.82	2.42
15	70	0.131	0.8	62	88	77	2.12	1.7	1.83
16	70	0.131	0.8	56	88	82	2.15	1.63	1.86
17	70	0.131	0.8	59	89	85	2.1	1.76	1.9
18	70	0.131	0.8	59	89	82	2.13	1.9	1.83
19	70	0.131	0.8	60	78	80	2.26	1.63	1.93
20	70	0.131	0.8	56	86	88	2.6	1.46	1.83

DISCUSSIONS

Figure 2 shows the variation of cutting temperature during DI water, neat cut oil, and emulsified fluid with experiment order. It has been observed that from low-speed 50m/min, the temperature will be minimum (experiment number 1-4) as increasing the speed to high-level 90m/min, the temperature is increasing due to more friction and wear of the tool (experiment number5-8). The depth of cut is the major factor to increase the temperature in the high depth of cut, low feed and high speed the temperature is increasing due to more deep contact of the tool with low movement and high speed, more thickness of chips, and high friction leads to the formation of high temperature. DI water gives better results for reducing temperature because of its low viscosity, high flowability, and heat absorbed rate more compare to other fluids. The maximum cutting temperature 108^{0}C will be obtained for high speed, medium level feed, and depth of cut for Neat Cut oil for same parameters temperature is 95^{0}C for emulsified fluid and 78^{0}C for DI Water.

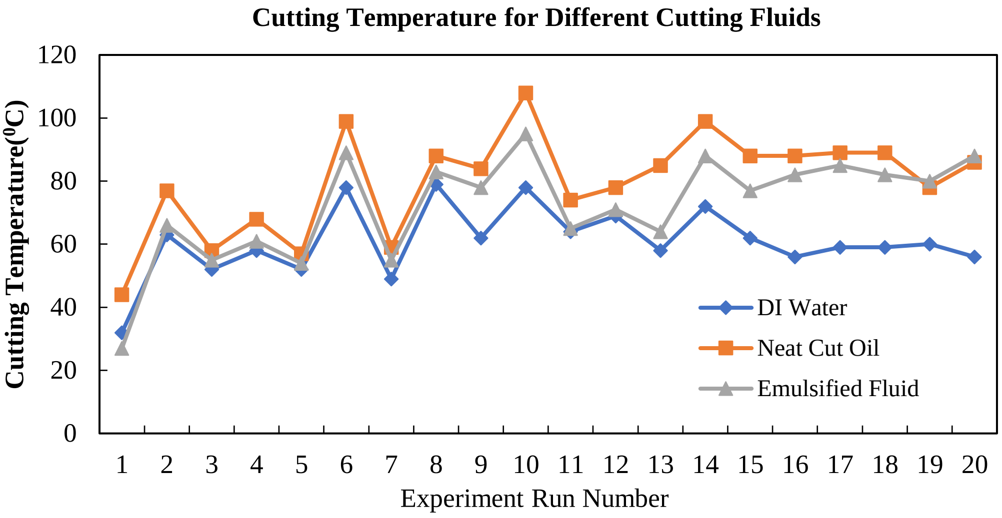


Figure 2. Experiment run number against cutting temperature for different cutting fluids

Figure 3 shows the variation of surface roughness during DI water, neat cut oil, and emulsified fluid with experiment order. It has been observed that from low speed, low feed, and low depth of cut, the surface roughness will be minimum because of the initial cut and sharpness of the tool, further increasing the feed and depth of cut roughness will be more due to built-up edge formation on the surface (experiment number 2-4) as increasing the speed to a high level the temperature in the cutting zone increases reduces the built-up edge leads to the formation of better surface finish (experiment number5-8). The feed is the most important factor affecting the surface roughness; increasing the feed rate tool movement will be fast and more friction more roughness. Improved surface finish obtained for emulsified fluid followed by DI water and neat cut oil because of its oil content in water more effective to reduce the friction and wear of the tool.

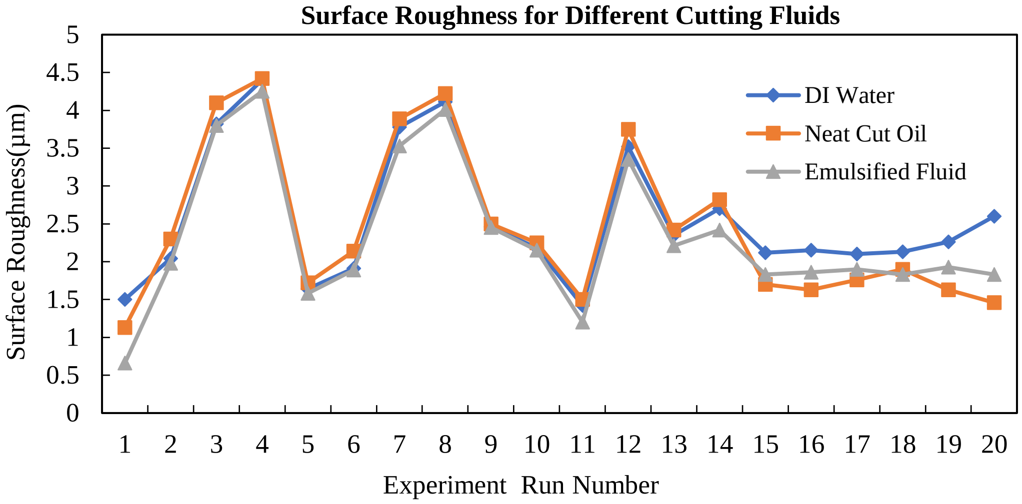


Figure 3. Experiment run number against surface roughness for different cutting fluids

Analysis of Variance (ANOVA) for Cutting Temperature

Analysis of variance (ANOVA is a powerful tool to recognize the significant parameter that affects the response of cutting temperature and surface roughness during turning of DSS-2205. The significance level of 5% and confidence level 95% are achieved in ANOVA. The significance for a given hypothesis test P-values under 0.0500 demonstrate model terms are significant [25-27].

Table 5. ANOVA for DI water as cutting fluid

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status	Contribution (%)
Model	1714.42	9	190.49	30.66	0.0001	significant	
A-Speed (Vc)	1.60	1	1.60	0.2575	0.6228		0.098
B-Feed (f)	8.10	1	8.10	1.30	0.2802		0.500
C-Doc(d)	1210.00	1	1210.00	194.74	0.0001	significant	74.83
AB	10.13	1	10.13	1.63	0.2306		0.626
AC	120.13	1	120.13	19.33	0.0013	significant	7.429
BC	78.13	1	78.13	12.57	0.0053	significant	4.831
A^2	0.0909	1	0.0909	0.0146	0.9061		0.005
B^2	122.78	1	122.78	19.76	0.0012	significant	7.593
C^2	3.84	1	3.84	0.6182	0.4500		0.237
Residual	62.13	10	6.21				3.842
Lack of Fit	34.80	5	6.96	1.27	0.3987	not significant	
Pure Error	27.33	5	5.47				
Total	1616.93	19					100

Table 6. ANOVA for neat cut oil as cutting fluid

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status	% of contribution
Model	6143.80	9	682.64	38.98	0.0001	significant	
A-Speed (Vc)	462.40	1	462.40	26.40	0.0004	significant	8.939
B-Feed (f)	193.60	1	193.60	11.05	0.0077	significant	3.742
C-Doc(d)	2280.10	1	2280.10	130.18	0.0001	significant	44.07
AB	162.00	1	162.00	9.25	0.0124	significant	3.131
AC	60.50	1	60.50	3.45	0.0927		1.169
BC	60.50	1	60.50	3.45	0.0927		1.169
A^2	260.20	1	260.20	14.86	0.0032	significant	5.030
B^2	918.20	1	918.20	52.43	0.0001	significant	17.75
C^2	600.14	1	600.14	34.27	0.0002	significant	11.60
Residual	175.15	10	17.51				3.385
Lack of Fit	85.81	5	17.16	0.9606	0.5171	not significant	
Pure Error	89.33	5	17.87				
Total	5172.79	19					100

Table 7. ANOVA for emulsified fluid as cutting fluid

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status	% of contribution
Model	7094.60	9	788.29	44.80	0.0001	significant	
A-Speed (Vc)	504.10	1	504.10	28.65	0.0003	significant	10.77
B-Feed (f)	22.50	1	22.50	1.28	0.2845		0.480
C-Doc(d)	828.10	1	828.10	47.06	0.0001	significant	17.69
AB	45.13	1	45.13	2.56	0.1404		0.964
AC	0.1250	1	0.1250	0.0071	0.9345		0.002
BC	55.13	1	55.13	3.13	0.1071		1.177
A^2	297.96	1	297.96	16.93	0.0021	significant	6.366
B^2	1800.96	1	1800.96	102.36	0.0001	significant	38.47
C^2	950.46	1	950.46	54.02	0.0001	significant	20.30
Residual	175.95	10	17.60				3.759
Lack of Fit	102.62	5	20.52	1.40	0.3607	not significant	
Pure Error	73.33	5	14.67				
Total	4680.41	19					100

Table 5, 6 and 7 shows ANOVA for DI water, neat cut oil and emulsified fluid for cutting temperature. In the present models, F-value 30.66, 38.98 and 44.80 implies that the developed models are significant. P-values less than 0.0500 indicate model terms are significant. During DI water C, AC, BC, B^2, during neat cut oil A, B, C, AB, A^2, B^2, C^2 and emulsified fluid A, C, A^2, B^2, C^2 model terms are significant. The depth of cut is the most influential factor affecting the cutting temperature in all the above models, 74.83% of contribution during DI water, 44.07% of contribution during neat cut oil, and 17.69 % of contribution during emulsified fluid followed by speed, feed, interaction factors, and square factors. In turning operation depth of cut are increases cutting temperature also increases because additional contact among tool tip and workpiece to cause more friction among the tool and workpiece, leads to the formation of the higher thickness of chips and also wear of the tool leads to increasing temperature in cutting zone. DI water is the better cutting fluid to reduce the temperature in the cutting zone compare to other fluids.

Fit Statistics for Models of Cutting Temperature

The R squared (R^2) is a correlation coefficient which measures the variation proportion in the data points ranging from -1 to +1. The value of R is close to 1 indicates that the model equation is significant. Table 8 shows the R^2 values for all cutting fluids the Predicted R^2 is in reasonable agreement with the Adjusted R^2 the difference is than 0.2 Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable the ratio Adequate Precision indicates an adequate signal for all three models.

Table 8. Fit Statistics for different cutting fluids

Type of Fluid	R^2	Adjusted R^2	Predicted R^2	Adequate Precision	Std. Dev	Mean	C.V. %
DI Water	0.9650	0.9335	0.8269	20.4246	2.49	53.85	4.63
Neat Cut Oil	0.9723	0.9473	0.8526	20.8989	4.19	75.45	5.55
Emulsified Fluid	0.9758	0.9540	0.8766	24.9005	4.19	64.35	6.52

Analysis of Variance (ANOVA) for Surface Roughness

Table 9, 10 and 11 shows ANOVA for DI water, neat cut oil and emulsified fluid for surface roughness. In the present models, F-value 42.16, 70.43 and 582.64 implies that the developed models are significant. P-values less than 0.0500 indicate model terms are significant. During DI water B, C, AB, C^2, during neat cut oil A, B, C, AC, A^2, B^2, C^2 and emulsified fluid B, C, AB, AC, BC, A^2, B^2, C^2 model terms are significant. The feed is the most influential factor affecting the surface roughness in all the above models 80.85% of contribution during DI water, 81.66% of contribution during neat cut oil, and 93.57 % of contribution during emulsified fluid followed by the depth of cut, speed, interaction factors, and square factors. It has been noted that feed increases the roughness also increases. When feed increases, the tool carriage will move faster than usual and extra friction between the tool and workpiece and chip and workpiece leads to a rough surface on the work. When the lower value of speed, feed, and depth of cut surface finish will be better, if increasing feed and depth of cut results in the formation of high temperature and heat-affected region poor finish of the workpiece, emulsified fluid is the better cutting fluid to reduce the surface roughness compare to other fluids.

Table 9. ANOVA for surface roughness DI water as cutting fluid

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status	% of contribution
Model	13.05	9	1.45	42.16	0.0001	significant	
A-Speed (Vc)	0.1254	1	0.1254	3.65	0.0852		0.966
B-Feed (f)	10.49	1	10.49	304.93	0.0001	significant	80.85
C-Doc(d)	0.8644	1	0.8644	25.14	0.0005	significant	6.662
AB	0.7813	1	0.7813	22.72	0.0008	significant	6.022
AC	0.0882	1	0.0882	2.56	0.1403		0.679
BC	0.0313	1	0.0313	0.9088	0.3629		0.241
A^2	0.0001	1	0.0001	0.0024	0.9621		0.0007
B^2	0.0575	1	0.0575	1.67	0.2252		0.443
C^2	0.1925	1	0.1925	5.60	0.0396	significant	1.483
Residual	0.3439	10	0.0344				2.650
Lack of Fit	0.1607	5	0.0321	0.8777	0.5551	not significant	
Pure Error	0.1831	5	0.0366				
Total	12.974	19					100

Table 10. ANOVA for surface roughness neat cut oil as cutting fluid

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status	% of contribution
Model	23.55	9	2.62	70.43	0.0001	significant	
A-Speed (Vc)	0.4410	1	0.4410	11.87	0.0063	significant	2.353
B-Feed (f)	15.30	1	15.30	411.83	0.0001	significant	81.66
C-Doc(d)	0.5290	1	0.5290	14.24	0.0036	significant	2.823
AB	0.0465	1	0.0465	1.25	0.2894		0.248
AC	0.2926	1	0.2926	7.88	0.0186	significant	1.561
BC	0.0210	1	0.0210	0.5655	0.4694		0.112
A^2	0.6676	1	0.6676	17.97	0.0017	significant	3.563
B^2	0.5762	1	0.5762	15.51	0.0028	significant	3.075
C^2	0.4914	1	0.4914	13.23	0.0046	significant	2.622
Residual	0.3716	10	0.0372				1.983
Lack of Fit	0.2630	5	0.0526	2.42	0.1770	not significant	
Pure Error	0.1086	5	0.0217				
Total	18.736	19					100

Table 11. ANOVA for surface roughness emulsified cutting fluid

Source	Sum of Squares	df	Mean Square	F-value	p-value	Status	% of contribution
Model	26.41	9	2.93	582.64	0.0001	significant	
A-Speed (Vc)	0.0221	1	0.0221	4.39	0.0627		0.085
B-Feed (f)	24.15	1	24.15	4795.76	0.0001	significant	93.57
C-Doc(d)	0.0902	1	0.0902	17.92	0.0017	significant	0.349
AB	0.0990	1	0.0990	19.66	0.0013	significant	0.383
AC	0.0435	1	0.0435	8.64	0.0148	significant	0.168
BC	0.1225	1	0.1225	24.33	0.0006	significant	0.474
A^2	0.2066	1	0.2066	41.03	0.0001	significant	0.800
B^2	0.3196	1	0.3196	63.47	0.0001	significant	1.238
C^2	0.7038	1	0.7038	139.78	0.0001	significant	2.727
Residual	0.0504	10	0.0050				0.195
Lack of Fit	0.0412	5	0.0082	4.51	0.0619	not significant	
Pure Error	0.0091	5	0.0018				
Total	25.807	19					100

Fit Statistics for Models of Surface Roughness

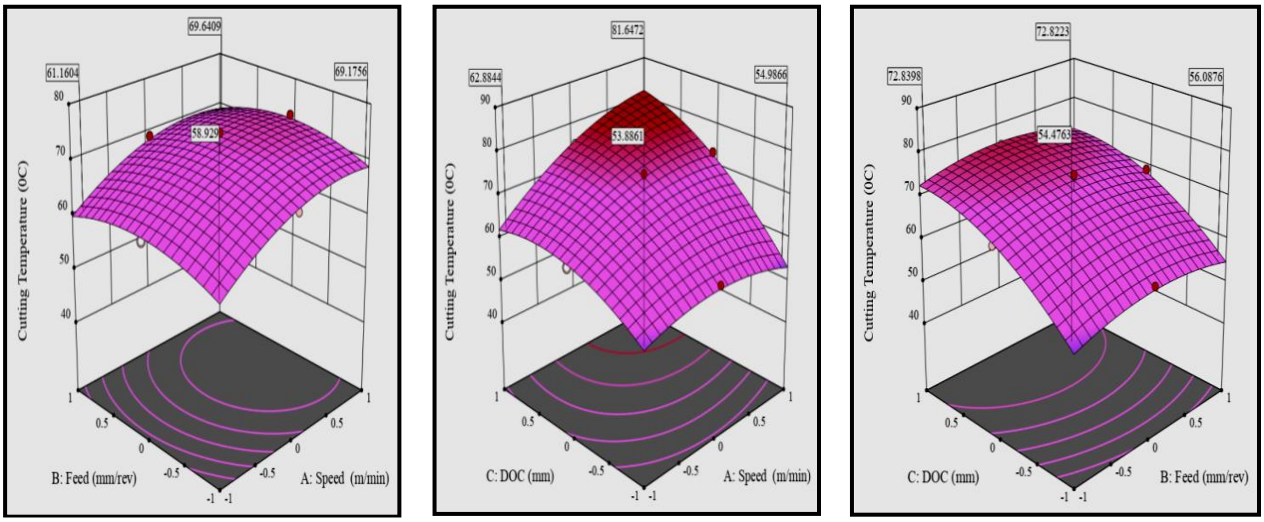
The R squared (R^2) is a correlation coefficient which measures the variation proportion in the data points ranging from -1 to +1. The value of R is close to 1 indicates that the model equation is significant. Table 12 shows the R^2 values for all cutting fluids the Predicted R^2 is in reasonable agreement with the Adjusted R^2 the difference is than 0.2 Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable the ratio Adequate Precision indicates an adequate signal for all three models.

Table 12. Fit statistics for different cutting fluids

Type of Fluid	R^2	Adjusted R^2	Predicted R^2	Adequate Precision	Std. Dev	Mean	C.V. %
DI Water	0.9743	0.9512	0.8704	26.4708	0.1854	2.37	7.82
Neat Cut Oil	0.9845	0.9705	0.8638	26.6008	0.1928	2.38	8.09
Emulsified Fluid	0.9981	0.9964	0.9844	73.6701	0.0710	2.16	3.29

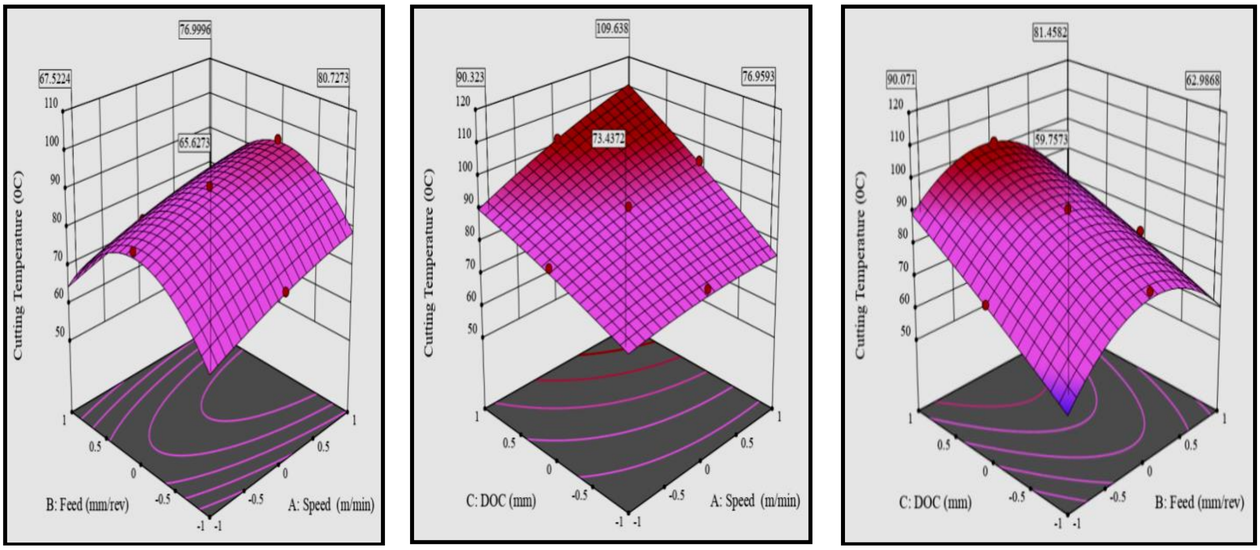
Effect of Process Parameters on Cutting Temperature

Figures 4, 5 and 6 (a to c) show the three-dimensional surface plots for the cutting temperature during turning with DI water, neat cut oil, and emulsified fluid. In the Figure 4(a), 5(a) and 6(a) clearly observe that when increasing the speed and feed temperature is increasing, with high speed and feed tool contact will be more on workpiece due to this high friction between too and work and wear of tool will be more causes increasing temperature in the cutting zone. In the Figure 4(b-c), 5(b-c) and 6(b-c) observed that depth of cut is the major affecting factor for increasing temperature with high speed and feed due to more friction between the tool &work, chip & work, high thickness of chips with more contact in rake face of the tool causes high wear rate of the tool leads to generate high temperature in cutting zone. DI water as cutting fluid reduces the temperature developed in the cutting zone due to low viscosity and high flowability of DI water better compare with neat cut oil and emulsified fluid.



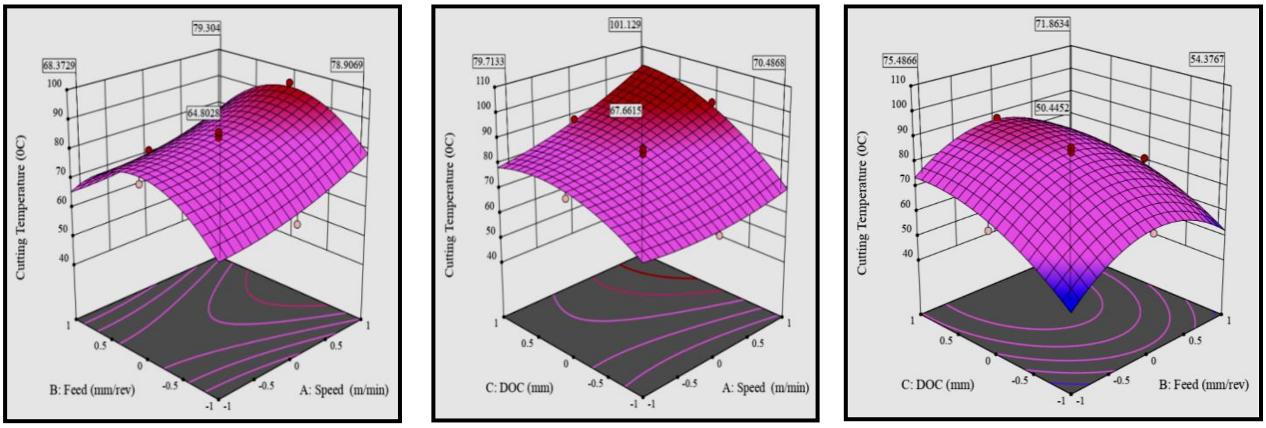
(a) (b) (c)

Figure 4. Three dimensional surface graphs for cutting temperature DI water cutting fluid



(a) (b) (c)

Figure 5. Three dimensional surface graphs for cutting temperature Neat cut oil cutting fluid

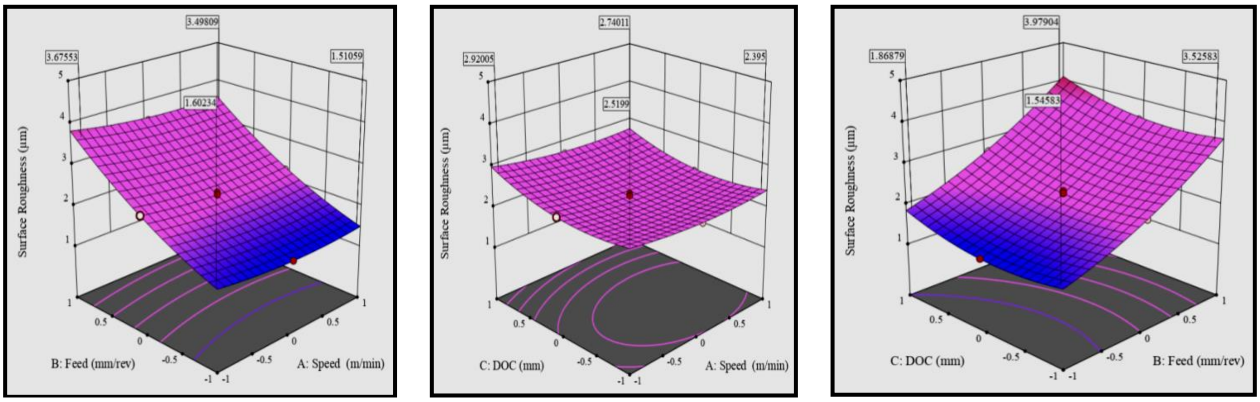


(a) (b) (c)

Figure 6. Three dimensional surface graphs for cutting temperature Emulsified cutting fluid

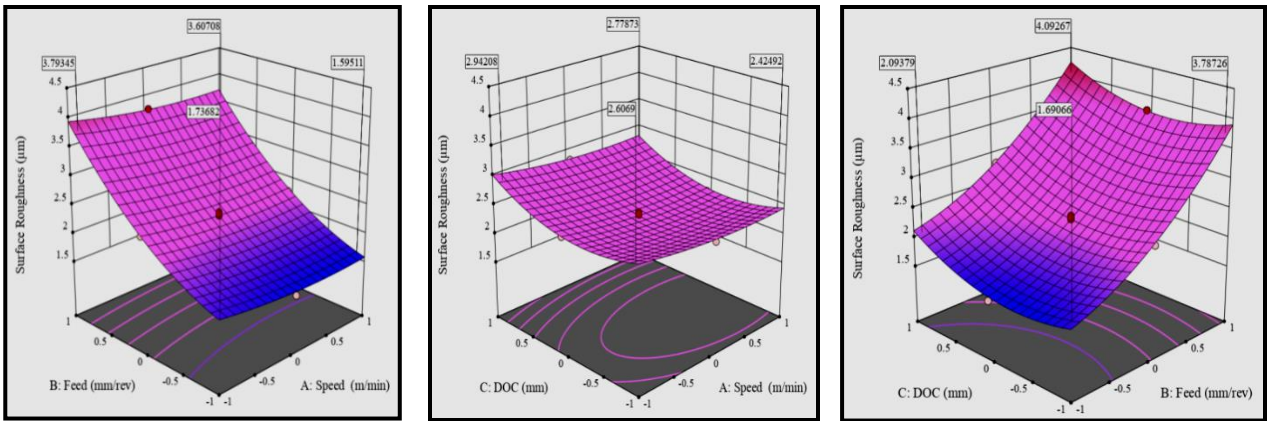
Effect of Process Parameters on Surface Roughness

Figures 7, 8 and 9 (a to c) show the three-dimensional surface plots for the surface roughness during turning with DI water, neat cut oil, and emulsified fluid. Figures 7(a), 8(a) and 9(a) clearly observe that when increasing the speed, surface roughness reduces, with low speed, low feed and low depth of cut surface finish will be better. During initial low speed with high feed and high depth of cut built-up edge formed on the material surface, the formation of a rough surface when increasing the speed temperature increases causes reduced the built-up edge, and surface roughness reduces. In the Figure 7(b), 8(b) and 9(b) observed that low depth of cut and low speed better surface finish increasing the depth of cut and speed surface roughness increases, due to more friction between tool and work and high tool wear rate. In the Figure 7(c), 8(c) and 9(c) observed that low feed and low depth of cut better surface finish but increasing the feed rate and depth of cut surface deteriorate due to high feed tool carriage will move faster than usual and more wear of the tool, more friction between work and tool leads to the formation of a rough surface. Emulsified fluid gives better surface roughness, because oil content in the water reduced friction and wear of tool more compare to other fluids.



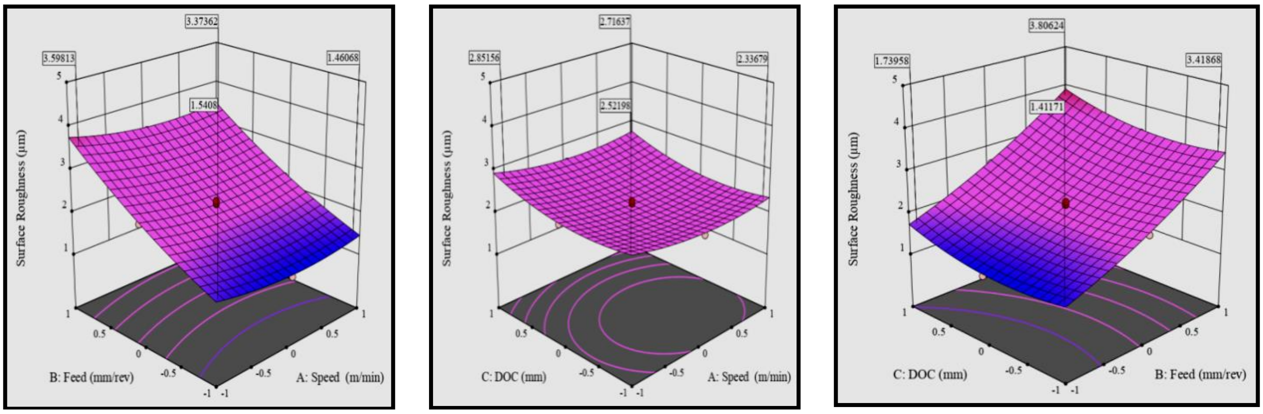
(a) (b) (c)

Figure 7. Three dimensional surface graphs for surface roughness DI water cutting fluid



(a) (b) (c)

Figure 8. Three dimensional surface graphs for surface roughness Neat cut oil cutting fluid



(a) (b) (c)

Figure 9. Three dimensional surface graphs for surface roughness Emulsified cutting fluid

Optimization

Numerical optimization was carried out under Desirability Function Analysis (DFA) using design expert-12 software. Among all three cutting fluids, results show that Deionized water is the best-cutting fluid for reduction of temperature, and emulsified fluid improves the surface finish for these two cutting fluids optimization process carried out to find the optimum cutting parameters. In the numerical optimization phase, we asked design expert software to minimize the cutting temperature and surface roughness to determine the optimum cutting speed, feed, and depth of cut. For this study, all the variables were set in range by keeping cutting temperature and surface roughness value at a minimum. The main function of DFA is first to convert the response to a desirability function in the range of zero to one [27]. When the response variable reaches its target or goal, desirability becomes one, and if the response variable is outside the adequate range, desirability becomes zero. In this present work, the target value for the responses is set as minimum value (smaller-the-better) [28].

Optimization of Process Parameters for Temperature during Deionized Water as Cutting Fluid

The objective of the optimization is to find the optimal values of input parameters to minimize the cutting temperature and surface roughness during turning of DSS-2205 under different cutting fluids. The constraints used for optimization are given in Tables 13 and 15 for Deionized water and emulsified cutting fluid. Table 14 and 16 shows that optimal solutions obtained based on decreasing desirability level.

Table 13. Range of input parameters and response

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Speed (m/min)	is in range	50	90	1	1	3
B: Feed (mm/rev)	is in range	0.051	0.205	1	1	3
C: Doc (mm)	is in range	0.4	1.2	1	1	3
Cutting Temperature (^{0}C)	minimize	32	79	1	1	3

Table 14. Iterative determination of optimum conditions

Number	Speed m/min	Feed mm/rev	Doc mm	Cutting Temperature	Desirability	
1	50	0.051	0.4	32.002	0.951	Selected
2	50	0.051	0.40	32.189	0.949	
3	50.16	0.051	0.4	32.043	0.949	
4	50	0.050	0.4	32.157	0.949	
5	50	0.051	0.40	32.480	0.947	
6	50.44	0.051	0.4	32.112	0.946	
7	50	0.052	0.4	32.430	0.945	
8	50	0.051	0.41	32.638	0.945	

Optimization of Process Parameters for Surface Roughness during Emulsified Cutting Fluid

Table 15. Range of input parameters and response

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Speed (m/min)	is in range	50	90	1	1	3
B: Feed (mm/rev)	is in range	0.051	0.205	1	1	3
C: Doc (mm)	is in range	0.4	1.2	1	1	3
Surface Roughness (µm)	minimize	0.66	4.25	1	1	3

Table 16. Iterative determination of optimum conditions

Number	Speed m/min	Feed mm/rev	Doc mm	Surface Roughness	Desirability	
1	50.00	0.051	0.4	0.660	0.995	selected
2	50.52	0.051	0.42	0.660	0.995	
3	50.72	0.051	0.42	0.666	0.995	
4	50.20	0.051	0.41	0.660	0.995	
5	50.32	0.050	0.41	0.660	0.994	
6	50.02	0.050	0.41	0.660	0.994	
7	51.02	0.051	0.42	0.674	0.994	
8	50	0.051	0.40	0.666	0.994	

Validation of Experiments

The optimum parameters selected based on desirability value near to one. After selecting the optimalparameter combination is to predict and validate the improvementof the performance quality with the selected optimumparameters. Validation experiments were repeated twice andthe average values were tabulated in below Table 17 and 18.

Table 17. Validation experiments for cutting temperature during Deionized water cutting fluid

Trial Number	Predicted values	Experimental values	% Error
1	32.002	30.96	3.24
2	32.189	33.55	4.05
3	32.043	33.21	3.51
4	32.157	33.12	2.90
5	32.480	34.12	4.80

Table 18. Validation experiments for surface roughness during Emulsified cutting fluid

Trial Number	Predicted values	Experimental values	% Error
1	0.660	0.68	2.94
2	0.660	0.69	4.35
3	0.666	0.7	4.86
4	0.660	0.71	7.04
5	0.660	0.67	1.49

CONCLUSIONS

In the present work, experimental investigation on the performance of DI water, neat cut oil, and emulsified fluid on cutting temperature and surface roughness during turning of duplex stainless steel-2205. According to the central composite design (CCF) of the RSM technique, twenty experiments were conducted with varying speed, feed, and depth of cut in three levels. Experimental results of cutting temperature and surface roughness were analyzed. The following conclusion is to be drawn.

1. The Analysis of variance (ANOVA) and a Significance level of factors for the experimental results revealed that the depth of cut is the most significant parameter for cutting temperature for all cutting fluids when increasing the depth of cut from low level (-1) to high level (+1) temperature is also increasing. The depth of cut contribution during DI water as cutting fluid is 74.83%, for neat cut oil 44.07% and emulsified fluid 17.69%.

2. Deionized water as cutting fluid gives better results in reduced the cutting temperature, followed by emulsified fluid and neat cut oil. The application of DI water as cutting fluid minimizes the friction and results in decreases in temperature rise. Further better thermal conductivity and viscosity of DI water carry the heat generated away from the cutting zone.
3. Feed rate is the most significant Parameter for surface roughness, followed by the depth of cut and speed for all cutting fluids. When increasing the feed rate from a low level (-1) to a high level (+1), surface roughness is also increasing. Feed rate contribution during DI water as cutting fluid is 80.65%, for Neat cut oil 81.66% and emulsified fluid 93.57%. Emulsified cutting fluid gives better results in reduced the surface roughness compares to that of neat cut oil and DI water.
4. Numerical optimization was carried out Under Desirability Function Analysis (DFA) for cutting temperature during deionized water as a cutting fluid the optimum cutting parameters are speed (50m/min), feed rate (0.051mm/rev) and depth of cut (0.4mm).The optimum parameters for surface roughness during emulsified cutting fluid are speed (50 m/min), feed rate (0.051mm/rev) and depth of cut (0.4mm).

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