Research Article

Experimental investigation of turning Al 7075 using Al_2O_3 nano-cutting fluid: ANOVA and TOPSIS approach

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Received: 14 April 2019 / Accepted: 9 November 2019 / Published online: 19 November 2019

Abstract
The evolution of modern industry tends to use aluminium based alloys due to its low density and high hardness. While machining aluminium, one of the major failure modes of cutting tool is the material being machined adheres to the tool cutting edge. This leads to poor surface quality characteristics. Tough different tool materials and tool coatings are available, achieving better machining parameter is still under research. Hence, in this work, Al 7075 is machined using CNC lathe under dry and with the nano lubricant of Al_2O_3 of 5%. The turning experiments were carried out in Siemens—CNC lathe to investigate the best operating conditions. There are 27 experiments based on full factorial approach is performed. The machining parameters are speed, feed and depth of cut. The output parameters are metal removal rate (MRR) and surface roughness (SR). The regression models developed from ANOVA are significant. To find best operating parameter TOPSIS is performed under each machining conditions. From the test results, it is concluded that the 1% of Al_2O_3 nano lubrication gives better value of both MRR and SR.

Keywords Nano-lubrication · ANOVA · TOPSIS · Al 7075 · Machining

1 Introduction

The use of aluminium in automotive and aircraft industries has grown rapidly in recent decades. It is estimated that quantity of aluminium used in passenger vehicle will be increased 70% in 2025 [1]. This due to that ability to coalesce of strength, lightness and their machining characteristics in a single material. Among various grades of aluminium, 7xxx are heat treatable with zinc as the primary alloying element used in aircraft, automobile, structural components and other superior strength applications. It possesses elevated lightweight potential due to their good specific tensile strength combined with good ultimate elongation [2]. The Al 7075 combines both strength and corrosion resistance properties and are widely used machine parts, artillery etc. [3]. The cost, disposal and environment norms are major motivations towards environmentally friendly machining [4]. The low melting point and chemical affinity of aluminium alloys it gives real challenge to find best machining parameters for researchers. While machining aluminium alloys (ductile material), chip-tool material adhesion greatly influences cutting temperature and poor quality surface roughness. The surface roughness can be improved by using diamond coating (CVD, chemical vapour deposition) tools after polishing [5]. The coated or diamond cutting tools contributes reduced machining forces and low adhesiveness due to their high hardness and low chemical affinity towards aluminium alloy [6]. The surface finish of Al-6061-T6 was analyzed by using the CCGT tool for 36 trial runs with orthogonal array and concluded that the feed rate and tool nose radius has more effect on surface finish than other parameters [7].

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Nine experiments were carried out with orthogonal array for S45C steel bar and found that the improvement in tool life and surface roughness from its initial cutting parameters to the optimal cutting parameters is about 250% [8]. The performances of micro drilling on Al 7075 using Electric discharge machine to analyze the tool wear rate and metal removal rate. From the 27 set experiments,the test results showed that the combination of maximum pulse on time and minimum pulse off time gives maximum MRR [9]. The performances was evaluated for four different types of vegetable-based cutting fluids (VBCF) over a commercial mineral cutting fluid during turning of Al 7075-T6. From the experimentation, authors indicated that the improvement in feed and radial force is 1.7–38.25% as compared to commercial fluid. The lowest average flank and nose radius using VBCF's are 0.09 and 0.15 mm respectively, where as these it is 0.18 and 0.15 mm in commercial fluids and finally concluded that turning of Al 7075-T6 using VBCF is better than commercial fluids [10].

In the turning of AA 6262-T6, cutting fluid with chlorine as additive with 10% produced minimum cutting force and better surface finish at cutting speed of 400 m/min, feed rate of 0.3 mm/rev and depth of cut of 2 mm than the sulphur additive and phosphor additive. The material AA 1050-O with mist lubrication indicated that an increase in flow rate of mist led to minimum feed forces but it increases the torque, power consumption and specific cutting pressure during drilling operation [11]. In AISI 304 turning with carbide tool it has been found that coconut oil extended the tool life with a better surface finish for machining at low and medium cutting speed. It was found that feed rate has 61.54% contribution on surface roughness and cutting speed has 46.49% contribution on tool wear [12]. The investigation on the effect of cutting parameters (cutting speed, feed rate and approach angle) on roughness in turning of Al 7075 hard ceramic composite (10 wt% SiC) and Al 7075 hybrid Composite (7 wt% SiC and 3 wt% graphite) using polycrystalline diamond tool (PCD) and found that the surface roughness is affected prominently by feed rate, cutting speed and interaction of feed rate and cutting speed [13]. The effects of MWCNTs and Al_2O_3 nano-cutting fluids on tool performance and chip morphology during turning of Inconel 718. The use of nano-fluids attributed to the increase in the shear angle. Consequently lower cutting forces are generated due to the increase in the shear angle and effective dissipation of heat which prevents the chip welding tendency while cutting without nano-additives [14]. The optimum process parameters are found in the EN 353 Alloy Steel and concluded that MQL is a better alternate cooling technique than flooded cooling where we can minimize the coolant utilization [15]. The performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools was studied [16]. Three cutting parameters namely, insert radius, feed rate, and depth of cut, are optimized with considerations of surface roughness. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness in turning AISI 1030 carbon steel. The new nano fluid was prepared [17] by mixing Al_2O_3 nanoparticles in conventional cutting fluid at different concentrations. The prepared nano fluid was characterized for its thermal conductivity and viscosity at all nano particle concentrations. Furthermore, its machining performance was examined in turning of AISI 1040 steel using Minimum Quantity Lubrication (MQL) technique. When nano cutting fluid was applied as mist in machining, reduction of ~ 47.8%, ~ 29.1% and ~ 25.5% in its average surface roughness of machined part as compared to dry, conventional mist and wet machining respectively.

The characterizing changes in the heat transfer capacities of nano fluids was studied with the inclusion of nanoparticles in the cutting fluids during machining [18]. Several parameters affect the condition of cutting tool, cutting forces and temperatures are found to be most influential. Thermal conductivities of the fluids increase with content of nano particles. Cutting fluids with inclusion of nano particles have enhanced heat transfer capacity up to 6% and decreases beyond. The effect of nano fluid MQL was analyzed with vegetable-based oil and ester oil as base fluids on cutting force and temperature in cylindrical turning of AISI 1045 medium carbon steel [19]. MQL technique can increase tool life and improve surface quality significantly in many machining processes as a result of lowered temperature and reduced friction at the tool-chip interface. Graphite oil-based nano fluid MQL obviously reduced cutting force and temperature when compared with dry cutting and MQL with the corresponding base oil. The decrease in cutting forces and tool wear rate, and a reduction in the negative environmental effects, owing to Al_2O_3 nanoparticle addition to MQL in machining of Inconel 600 alloy [20]. This experimental results showed that surface roughness, temperature, cutting force, and tool wear can be reduced significantly by machining Inconel 600 alloy under the condition of MQL with (6 vol% of Al_2O_3 particle) nanofluids than dry and MQL. The comparative study of tool wear, cutting force, surface roughness, and chip thickness among dry machining, machining with conventional cutting fluid as well as nano-cutting fluid has been undertaken for the material AISI 4340 [21]. It was found that adding 1% Al_2O_3 nanoparticles (by volume) to the conventional cutting fluid greatly enhances its wettability characteristics compared to pure water and conventional cutting fluid. The use of conventional cutting fluids has caused ecological and health problems. So many researchers have been carried out with (1) dry machining and (2) environmentally stable lubricant. If there is no coolant or lubricant, the adhesion between workpiece and tool is more which in turn causes high thermal load [22]. Composites with different combination of Al 6061, AZ31 and rock dust and studied the wear characteristics [23]. The test results showed that a composite of 97% of Al (6061-T6), 1% Mg (AZ31) and 2% of rock dust produced less wear. To find the best value of operating parameter for each sample, ANN-GA is used. The surface roughness characteristics was studied for Inconel 718 using two different tools inserts of Titanium (DNMG 15-06-04) and Carbide (TNMG 15-06-04) are used for machining [24]. These two tools are having different angles of approach to the work piece and have its own significance in quality of machining. The test result indicated that for low speed application Titanium tools are preferred and high speed applications Carbide tools are ideal.

Though different types of coating and tool materials, coolants are available for machining, still achieving best machining parameter is great task for researchers. Hence, in this work dry machining along with environmentally stable nanolubricant having PH value of 7 is used to find the machining characteristics.

2 Materials

2.1 Materials for machining

In this work Al 7075 aluminium alloy is considered for finding best machining characteristics. It's strength is comparable to many steels and it has good fatigue strength and average machinability. It has lower resistance to corrosion than many other aluminium alloys. The Table 1 shows the chemical composition of Al 7075.

2.2 Cutting tool

In this work, DCMT 070204 cutting tool is used, which is having external and internal machining of small, long and slender components. Sharp cutting edges and excellent chip control ensure a soft cutting action and low cutting forces, providing an excellent surface finish to the component.

Table 1 Chemical composition of Al 7075

Element	Al	Zn	Mg	Cu	Cr
Content (%)	90	5.6	2.5	1.6	0.23

2.3 Coolant

In order to carry out machining under wet condition, a nanolubriant of Al_2O_3 with 0.5% and 1% is used. The Al_2O_3 is mixed with standard coolant with weight ratio. The PH of proposed coolant is measured using PH meter and its value is maintained at 7 by adding water. The Al_2O_3 nano fluid is used to increase the surface finish and act as coolant.

3 Machining

To find machining characteristics, Al_2O_3 of bar dia 50 mm is used for the machining length of 50 mm. The machining is carried out in CNC MTAB Lathe of Siemens make and it is shown in the Fig. 1. The machining is carried out under dry, 0.5% and 1% of nano fluids by its volume. The Table 2 shows the operating range of CNC Siemens lathe. The MRR stands for Material Removal Rate and it is defined as the ratio of the volume of removal of metal to the time duration taken for machining. The selection of MRR as one of the output response is the importance of production rate in every industries to increase the volume of production. Ra stands for surface roughness (SR) and it plays the important role in the machining. Smooth finish which increases the life of the products.

To analyze the machining characteristics, the following process parameters with three levels are taken and it is shown in Table 3.

For each input parameter, three levels are selected. Therefore the total numbers of experimental runs are $3 \times 3 \times 3 = 27$. The output parameters are metal removal rate and surface roughness. Among the experimental designs such as Factorial method, Taguchi Orthogonal array method and Response surface method, the full factorial method having advantage like the experiments were carried out in all the possible causes giving better result even though the experimentation cost is more. Hence in this work the full factorial approach is considered. The Table 4 shows L27 array with coded and actual values after experimentation.

4 Results and discussion

The results from the ANOVA are taken for all the three conditions like dry, 0.5% and 1% nano fluid and are shown below.

Fig. 1 Typical CNC Siemens lathe machine

Table 2 CNC Siemens lathe machine specification

Sl. no.	Parameter	Range
1	Spindle speed	0–2000 rpm
2	Feed rate	0–2 m/min
3	Depth of cut (DoC)	0–10 mm
4	Length × breath × height	1970 × 1000 × 1720 mm

Table 3 Input parameters range for machining

Level	Speed (Rpm)	Feed (m/min)	Depth of cut (mm)
1	1250	0.05	0.4
2	1500	1	0.6
3	1750	0.15	0.8

4.1 Investigation on MRR

The Tables 5, 6 and 7 shows the ANOVA table for metal removal rate under dry, 0.5% and 1% of nano lubrication. For machining under all three conditions denotes that the models are significant for MRR. There is only a 0.01% change that the model F value could be large due to noise. The value of Prob > F is less than 0.05 indicates that model terms are significant. The regression model for MRR under all three conditions are shown in Eqs. 1–3.

4.1.1 MRR under dry condition

Regression model for MRR

$$\begin{aligned} MRR = &+2.82 + 0.43 * A + 1.24 * B + 0.80 * C \\ &+ 0.17 * A * B + 0.12 * A * C \\ &+ 0.36 * B * C - 0.12 * A^2 \\ &- 0.18 * B^2 + 0.26 * C^2. \end{aligned} \quad (1)$$

Figure 2(i) shows the effect of feed and speed on MRR. From the figure it is observed that MRR is low at feed rate 0.05 m/min and speed 1250 rpm. While increasing the speed from 1250 to 1750 rpm at the feed rate of 0.5 m/min, the improvement in MRR is less significant. The maximum MRR is achieved at a feed rate 0.15 m/min and speed 1750 rpm.

Figure 2(ii) shows effect of depth of cut and speed on MRR. From the figure it is understand that MRR is low at depth of cut is 0.4 mm and speed 1250 rpm. For the depth of cut point 0.05 mm is increased from 1250 to 1750 rpm. The increased in MRR is at the speed 1250 and depth of cut is 0.4 to 0.8 mm. It changes the MRR is the constant speed at depth of cut increases, MRR also increased. The maximum MRR is achieved at a depth of cut is 0.8 mm and speed is 1750 rpm.

Figure 2(iii) shows the effect of feed and depth of cut on MRR. From the figure it is observed that MRR is low at a feed rate 0.05 m/min and depth of cut 0.7 mm. For the feed of 0.05 m/min and the speed is increased from 0.7 to 0.8 mm. The increased in MRR is at the depth of cut 0.7 mm and feed 0.05 to 0.15 m/min. It changes in MRR is the constant for the depth of cut at feed increases and depth of cut increases. The maximum MRR is achieved at a feed 0.15 m/min and depth of cut 0.8 mm.

The contribution chart Fig. 3 shows the input parameter feed creates major role for the output parameter MRR. It influence around 54% on MRR and follows that depth of cut and speed influence the MRR. In general as reported by the many researchers, the depth of cut and

Table 4 Experimental values with input and output parameters

Job no.	Speed	Feed	Depth of cut	1%		0.50%		DRY	
				MRR cc/min	Ra microns	MRR cc/min	Ra microns	MRR cc/min	Ra microns
1	1250	0.05	0.4	0.8898	0.36	1.84	0.39	0.918	0.37
2	1250	0.05	0.6	0.9744	0.37	1.27	0.43	1.631	0.26
3	1250	0.05	0.8	1.6956	0.42	1.72	0.42	1.6596	0.38
4	1250	0.1	0.4	1.6698	0.52	1.64	0.64	1.7154	0.7
5	1250	0.1	0.6	2.478	0.49	2.4	0.54	2.5236	0.68
6	1250	0.1	0.8	3.1722	0.47	3.22	0.62	3.172	0.53
7	1250	0.15	0.4	2.3376	0.53	2.25	0.88	2.391	1.22
8	1250	0.15	0.6	3.4158	0.84	3.38	1.04	3.4908	1.1
9	1250	0.15	0.8	4.2918	0.82	4.3	0.85	4.281	1.11
10	1500	0.05	0.4	1.0866	0.35	1.04	0.4	1.08216	0.39
11	1500	0.05	0.6	1.5576	0.37	1.49	0.32	1.062	0.29
12	1500	0.05	0.8	2.0526	0.37	2.03	0.32	2.043	0.32
13	1500	0.1	0.4	1.9572	0.46	1.88	0.58	1.9572	0.5
14	1500	0.1	0.6	2.9088	0.48	2.08	0.48	2.9982	0.53
15	1500	0.1	0.8	3.7098	0.44	3.71	0.4	3.7272	0.49
16	1500	0.15	0.4	2.763	0.85	2.71	1.13	2.7882	1.04
17	1500	0.15	0.6	3.981	1.02	3.91	1.07	4.0818	1.11
18	1500	0.15	0.8	5.2122	0.81	5.24	0.87	5.25	1.02
19	1750	0.05	0.4	1.2642	0.3	1.21	0.27	1.258	0.29
20	1750	0.05	0.6	1.7628	0.41	1.69	0.33	1.8174	0.35
21	1750	0.05	0.8	2.25	0.38	2.33	0.39	2.3376	0.4
22	1750	0.1	0.4	2.2266	0.49	2.15	0.57	2.158	0.48
23	1750	0.1	0.6	3.2532	0.43	3.21	0.48	3.345	0.55
24	1750	0.1	0.8	4.1988	0.46	4.24	0.62	4.26	0.44
25	1750	0.15	0.4	3.1884	1.11	3.1	1.07	3.174	1.07
26	1750	0.15	0.6	4.6548	0.83	4.54	1.01	4.6686	1.14
27	1750	0.15	0.8	5.9241	0.9	5.92	1.1	6.021	1.08

Table 5 Anova table for MRR under dry condition

Source	Sum of squares	Df	Mean square	F value	*p* value Prob > F
Model	43.77	9	4.86	39.18	< 0.0001*
A-speed	3.38	1	3.38	27.19	< 0.0001
B-feed	27.46	1	27.46	221.18	< 0.0001
C-depth of cut	10.76	1	10.76	86.64	< 0.0001
AB	0.33	1	0.33	2.69	0.1193
AC	0.17	1	0.17	1.37	0.2580
BC	1.60	1	1.60	12.87	0.0023
A^2	0.071	1	0.071	0.57	0.4590
B^2	0.16	1	0.16	1.26	0.2768
C^2	4.00	1	4.00	32.19	< 0.0001
Residual	2.11	17	0.12		

*Indicates significant value

Table 6 Anova table of MRR In 0.5% nano fluid

Source	Sum of squares	Df	Mean square	F value	*p* value Prob > F
Model	42.53	9	4.73	110.04	< 0.0001*
A-speed	2.25	1	2.25	52.35	< 0.0001
B-feed	23.89	1	23.89	556.21	< 0.0001
C-depth of cut	12.33	1	12.33	287.08	< 0.0001
AB	0.87	1	0.87	20.27	0.0003
AC	0.53	1	0.53	12.30	0.0027
BC	2.44	1	2.44	56.76	< 0.0001
A^2	0.092	1	0.092	2.13	0.1625
B^2	0.017	1	0.017	0.39	0.5401
C^2	0.12	1	0.12	2.87	0.1084
Residual	0.73	17	0.043		

*Indicates significant value

Table 7 ANOVA table of MRR in 1% nano fluid

Source	Sum of squares	Df	Mean square	F value	*p* value Prob > F
Model	46.22	9	5.14	206.21	< 0.0001*
A-speed	2.93	1	2.93	117.50	< 0.0001
B-feed	27.72	1	27.72	1113.17	< 0.0001
C-depth of cut	13.02	1	13.02	522.88	< 0.0001
AB	0.52	1	0.52	20.85	0.0003
AC	0.31	1	0.31	12.60	0.0025
BC	1.63	1	1.63	65.28	< 0.0001
A^2	0.013	1	0.013	0.53	0.4774
B^2	0.057	1	0.057	2.30	0.1479
C^2	0.020	1	0.020	0.81	0.3808
Residual	0.42	17	0.025		

*Indicates significant value

feed are affecting the material removal rate during metal cutting process. Material removal directly proportional to the depth of cut and feed rate. Hence nonetheless of the speed, the depth of cut and feed affecting the roughness of the workpiece and feed has much significance [25].

4.1.2 MRR under 0.5% nano fluid condition

Regression model for MRR

$$\begin{aligned} MRR = {} & +2.55 + 0.35 * A + 1.15 * B + 0.83 * C \\ & + 0.27 * A * B + 0.21 * A * C \\ & + 0.45 * B * C + 0.12 * A^2 \\ & + 0.053 * B^2 + 0.14 * C^2 \end{aligned} \quad (2)$$

Figure 4(i) shows the effect of feed and speed on MRR. From the figure it is observed that MRR is low at feed rate 0.05 m/min and speed 1250 rpm. For the Fig. 4(i) it is observed that feed of 0.05 point is increased from 1250 to 1750. The MRR is increased at the speed 1250 and feed is increased at 0.05 to 0.15 m/min. It changes in MRR the constant speed at feed increases, MRR also increases. The maximum MRR is achieved at a feed rate 0.15 m/min and speed 1750 rpm.

Figure 4(ii) shows effect of depth of cut and speed on MRR. From the figure it is revealed that MRR is low at depth of cut is 0.4 mm and speed 1250 rpm. For the depth of cut point 0.05 mm is increased from 1250 to 1750 rpm. The increased in MRR is at the speed 1250 and depth of cut is 0.4 to 0.8 mm. The changes in MRR is the constant speed at depth of cut increases, MRR also increased. The maximum MRR is achieved at a depth of cut is 0.8 mm and speed is 1750 rpm.

Figure 4(iii) shows the effect of feed and depth of cut on MRR. From the figure it is releaved that MRR is low at a feed rate 0.05 m/min and depth of cut 0.7 mm. For the feed of 0.05 m/min and the speed is increased from 0.7 to 0.8 mm. The increased in MRR is at the depth of cut 0.7 mm and feed 0.05 to 0.15 m/min. The changes in MRR is constant

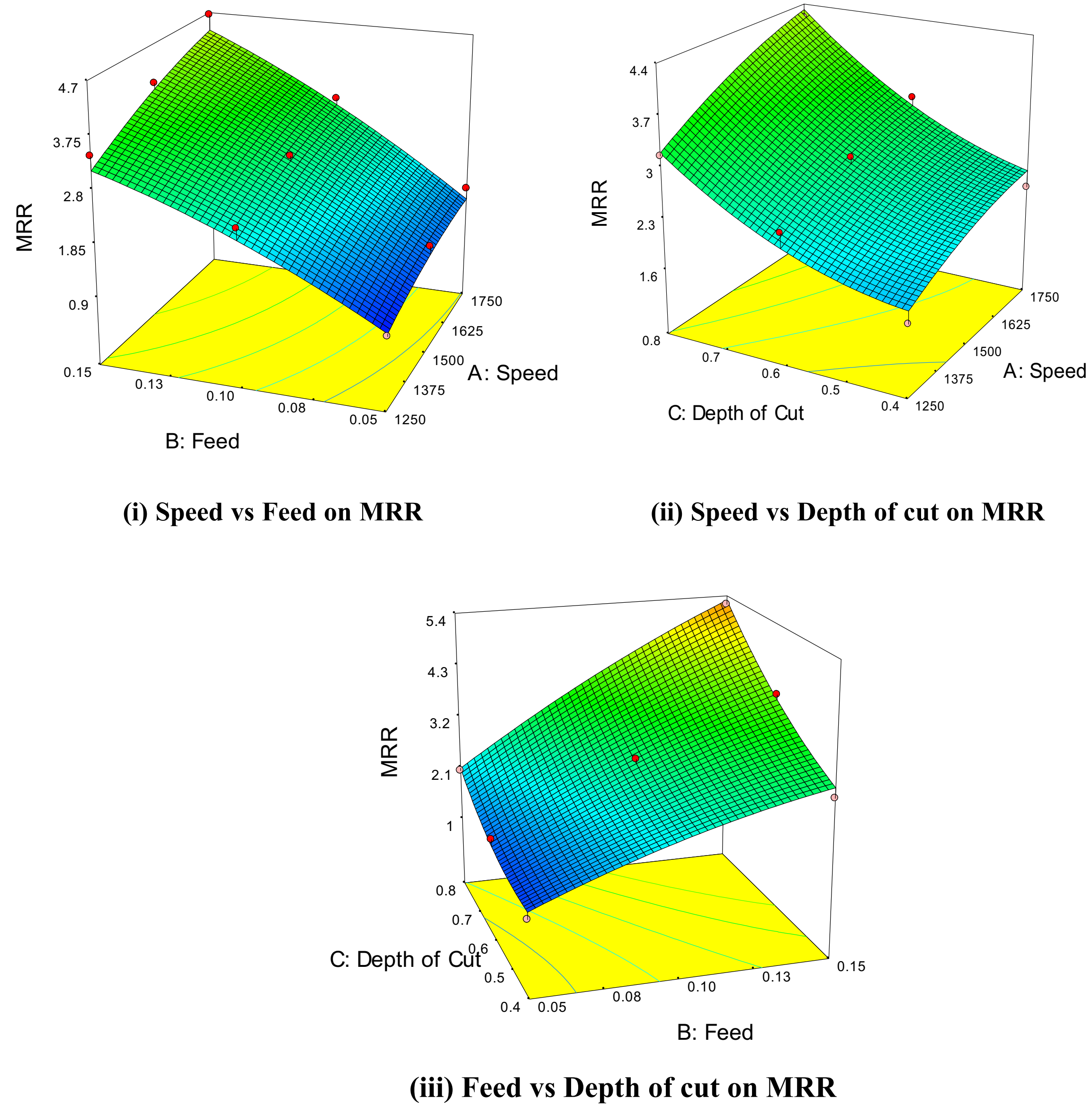
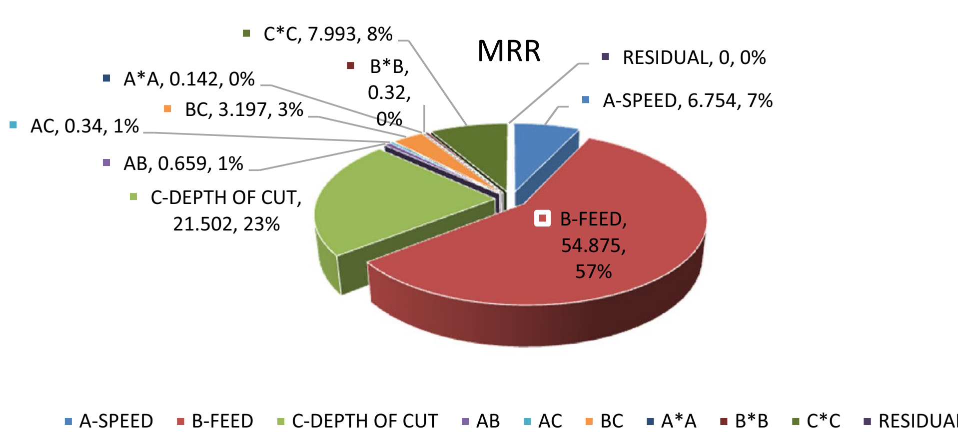


Fig. 2 (i) Speed versus feed on MRR, (ii) speed versus depth of cut on MRR and (iii) feed versus depth of cut on MRR

Fig. 3 Contribution plot for MRR in dry condition



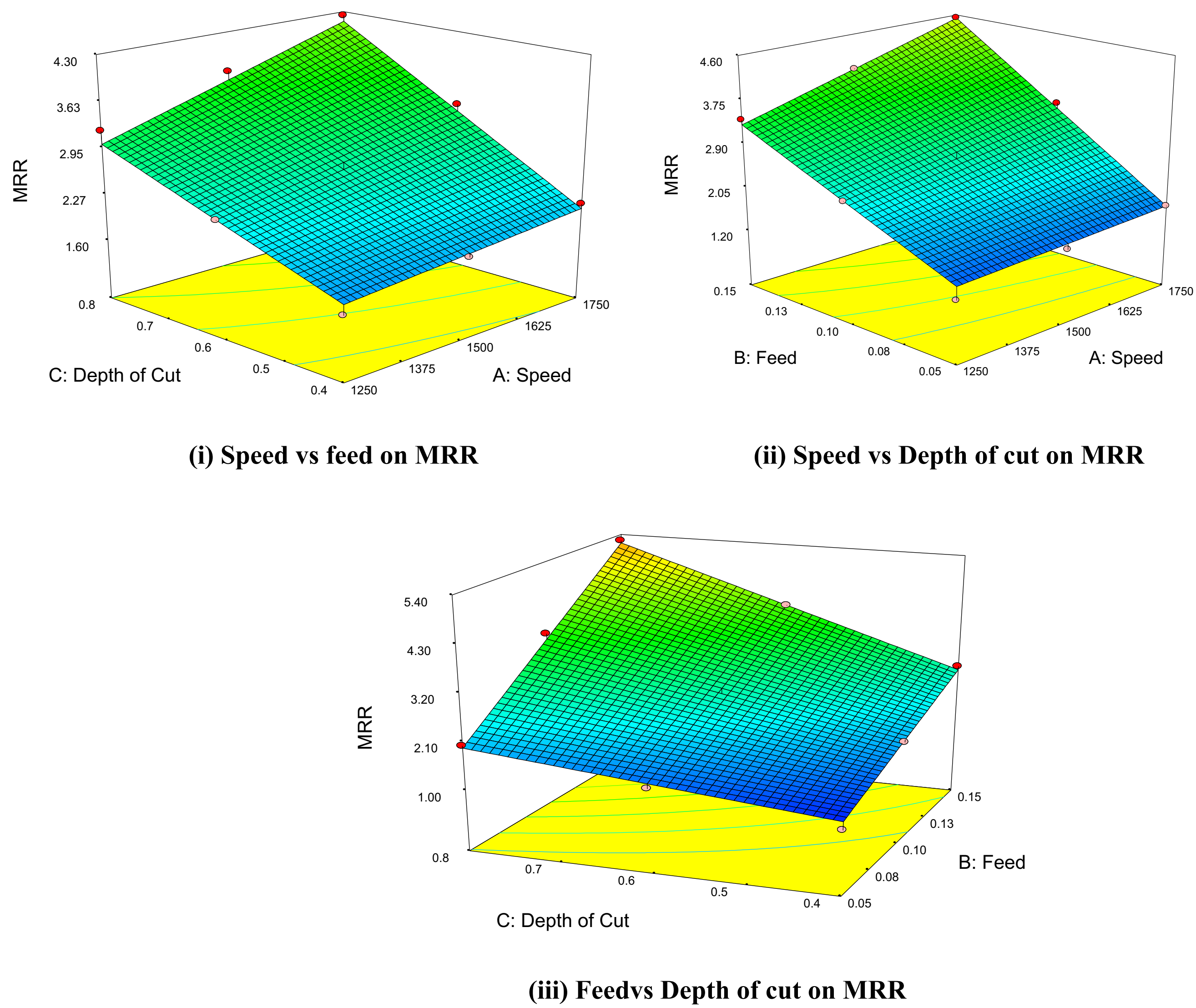
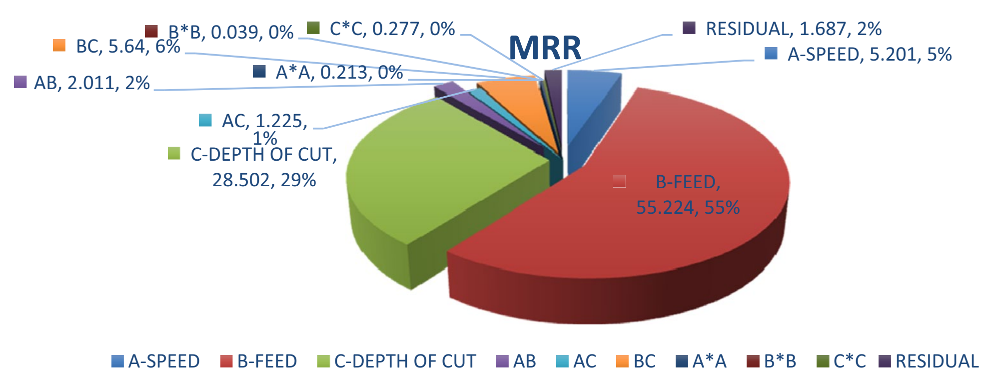


Fig. 4 (i) Speed versus feed on MRR, (ii) speed versus depth of cut on MRR and (iii) feed versus depth of cut on MRR

Fig. 5 Contribution plot for MRR on 0.5%



in the depth of cut at the feed increases therefore depth of cut increases. The maximum MRR is achieved at a feed 0.15 m/min and depth of cut 0.8 mm. The MRR maximize the point at 0.8 to 5.40 cc/min.

The contribution chart Fig. 5 shows the input parameter feed creates major role for the output parameter MRR. It influence around 55% on MRR and follows that depth of cut and speed influence the MRR. The similar results also reported by the previous researchers that among the three parameters depth of cut and feed plays vital role on the response during machining of materials [26].

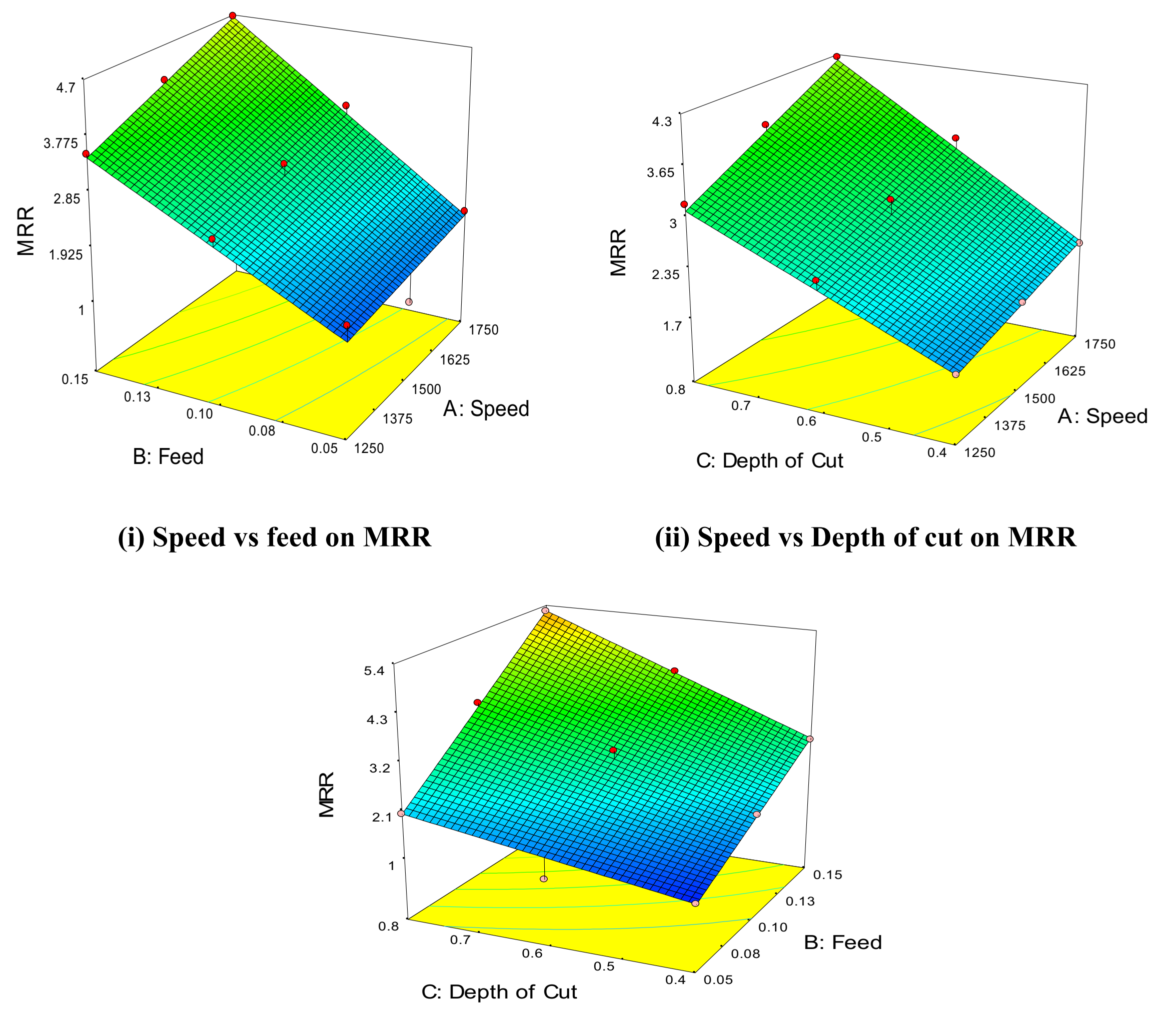
4.1.3 MRR under 1% nano fluid condition

Regression model for MRR

$$
\begin{aligned}
MRR = &+2.88 + 0.40 * A + 1.24 * B + 0.85 * C \\
&+ 0.21 * A * B + 0.16 * A * C \\
&+ 0.37 * B * C + 0.047 * A^2 \\
&- 0.098 * B^2 - 0.058 * C^2
\end{aligned}
\quad (3)
$$

Figure 6(i) shows the effect of feed and speed on MRR. From the Fig. 6(i) it is understand that MRR is low at feed rate 0.05 m/min and speed 1250 rpm. It is observed that feed of 0.05 point is increased from 1250 to 1750. The MRR is increased at the speed 1250 and feed is increased at 0.05 to 0.15 m/min. It changes in MRR the constant speed at feed increases, MRR also increases. The maximum MRR is achieved at a feed rate 0.15 m/min and speed 1750 rpm.

Figure 6(ii) shows effect of depth of cut and speed on MRR. From the figure it is observed that MRR is low



(i) Speed vs feed on MRR

(ii) Speed vs Depth of cut on MRR

(iii) Feed vs Depth of cut on MRR

Fig. 6 (i) Speed versus feed on MRR, (ii) speed versus depth of cut on MRR and (iii) feed versus depth of cut on MRR at depth of cut is 0.4 mm and speed 1250 rpm. For the depth of cut point 0.05 mm is increased from 1250 to 1750 rpm. The increased in MRR is at the speed 1250 and depth of cut is 0.4 to 0.8 mm. The changes in MRR is the constant speed at depth of cut increases, MRR also increased. The maximum MRR is achieved at a depth of cut is 0.8 mm and speed is 1750 rpm.

Figure 6(iii) shows the effect of feed and depth of cut on MRR. From the figure it is releaved that MRR is low at a feed rate 0.05 m/min and depth of cut 0.7 mm. For the feed of 0.05 m/min and the speed is increased from 0.7 to 0.8 mm. The increased in MRR is at the depth of cut 0.7 mm and feed 0.05 to 0.15 m/min. The changes in MRR is constant in the depth of cut at the feed increases therefore depth

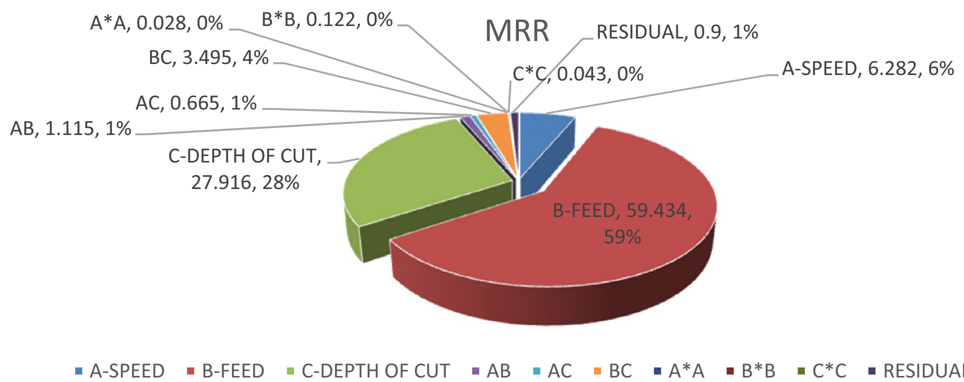


Fig. 7 Contribution plot for MRR on 1%

Table 8 ANOVA table for Ra in dry condition

Source	Sum of squares	Df	Mean square	F value	p value Prob > F
Model	2.81	9	0.31	84.25	< 0.0001*
A-speed	0.016	1	0.016	4.37	0.0520
B-feed	2.60	1	2.60	701.96	< 0.0001
C-depth of cut	7.738E−003	1	7.738E−003	2.09	0.1667
AB	2.506E−003	1	2.506E−003	0.68	0.4223
AC	9.816E−003	1	9.816E−003	2.65	0.1221
BC	2.506E−003	1	2.506E−003	0.68	0.4223
A^2	6.225E−003	1	6.225E−003	1.68	0.2123
B^2	0.16	1	0.16	44.08	< 0.0001
C^2	1.852E−004	1	1.852E−004	0.050	0.8258
Residual	0.063	17	3.706E−003		

*Indicates significant value

Table 9 Ra in 0.5% nano lubrication

Source	Sum of squares	Df	Mean square	F value	p value Prob > F
Model	1.27	9	0.14	16.96	< 0.0001*
A-speed	0.013	1	0.013	1.61	0.2218
B-feed	1.07	1	1.07	128.54	< 0.0001
C-depth of cut	4.924E−004	1	4.924E−004	0.059	0.8104
AB	0.042	1	0.042	5.07	0.0379
AC	0.018	1	0.018	2.13	0.1630
BC	1.200E−003	1	1.200E−003	0.14	0.7083
A^2	2.119E−003	1	2.119E−003	0.26	0.6197
B^2	0.086	1	0.086	10.39	0.0050
C^2	1.053E−003	1	1.053E−003	0.13	0.7259
Residual	0.14	17	8.292E−003		

*Indicates significant value

Table 10 Ra in 1% nano fluid

Source	Sum of squares	Df	Mean square	F value	p value Prob > F
Model	2.01	9	0.22	35.52	< 0.0001*
A-speed	5.000E−005	1	5.000E−005	7.963E−003	0.9299
B-feed	1.84	1	1.84	292.52	< 0.0001
C-depth of cut	6.422E−003	1	6.422E−003	1.02	0.3260
AB	0.036	1	0.036	5.78	0.0279
AC	4.033E−003	1	4.033E−003	0.64	0.4339
BC	9.075E−003	1	9.075E−003	1.45	0.2458
A^2	4.817E−003	1	4.817E−003	0.77	0.3933
B^2	0.11	1	0.11	17.41	0.0006
C^2	2.667E−004	1	2.667E−004	0.042	0.8392
Residual	0.11	17	6.279E−003		

*Indicates significant value

of cut increases. The maximum MRR is achieved at a feed 0.15 m/min and depth of cut 0.8 mm.

The contribution chart Fig. 7 shows the input parameter feed creates major role for the output parameter MRR. It influence around 59% on MRR and follows that depth of cut and speed influence the MRR.

4.2 Investigation on surface roughness

The Tables 8, 9 and 10 shows the ANOVA table for surface roughness under dry, 0.5% and 1% of nano lubrication. For machining under all three conditions denotes that the models are significant for surface roughness. There is only a 0.01% change that the model F value could be large due to noise. The value of Prob > F is less than 0.05 indicates that model terms are significant. The regression model for Surface roughness under all three conditions are shown in Eqs. 4–6.

4.2.1 SR under dry condition

Regression model for Ra

$$\begin{aligned} Ra = &+0.54 - 0.030 * A + 0.38 * B - 0.021 * C \\ &- 0.014 * A * B + 0.029 * A * C \\ &- 0.014 * B * C + 0.032 * A^2 + 0.17 * B^2 \\ &- 5.556E{-}003 * C^2 \end{aligned} \tag{4}$$

Figure 8(i) shows the effect of speed and depth of cut on Ra. From the figure it is understand that Ra is high at speed 1250 rpm and DOC 0.4 mm. For the Fig. 8(i) it is observed that speed of 1250 point is increased and the depth of cut 0.8 to 0.4 m/min is decreased. The Ra is increased at the speed 1250 and depth of cut is decreased at a point 0.8 m/min. It changes in Ra the constant speed at speed increases, Ra also increases. The maximum Ra is achieved at a depth of cut is 0.8 m/min and speed 0.4 mm.

Figure 8(ii) shows effect feed and depth of cut on Ra. From the figure it is revealed that Ra is low at depth of cut is 0.4 mm and feed 0.05 m/min. For the depth of cut point 0.05 mm is increased from 0.05 to 0.15 m/min. The increased in Ra is at the feed 0.05 m/min and depth of cut is 0.4 to 0.8 mm. The changes in Ra is the constant speed at depth of cut increases, Ra also increased. The maximum Ra is achieved at a depth of cut is 0.8 mm and feed is 0.15 m/min.

Figure 8(iii) shows the effect of speed and feed on Ra. From the figure (iii) it is observed that Ra is low at speed 1250 rpm and feed rate 0.05 m/min. For the figure (iii) it is observed that speed of 1250 rpm point is increased from the feed 0.05 to 0.15 m/min. The Ra is increased at the feed 0.05 m/min and speed is increased at 1250 to 1750 rpm. It changes in Ra the constant speed at feed increases, Ra also increases. The maximum Ra is achieved at a speed rate 1750 rpm and feed rate is 0.15 m/min.

The contribution chart shows the input parameter feed creates major role for the output parameter Ra. It influence around 90% on Ra and follows that depth of cut and speed influence the Ra (Fig. 9).

4.2.2 Ra for 0.5% nano lubrication

Regression model for Ra

$$\begin{aligned} Ra = &+0.50 + 0.027 * A + 0.24 * B + 5.437E{-}003 * C \\ &+ 0.059 * A * B - 0.038 * A * C \\ &- 1.000E002 * B * C - 0.021 * A^2 + 0.13 * B^2 \\ &- 4.215E{-}003 * C^2 \end{aligned} \tag{5}$$

Figure 10(i) shows the effect of speed and depth of cut on Ra. From the figure it is observed that Ra is high

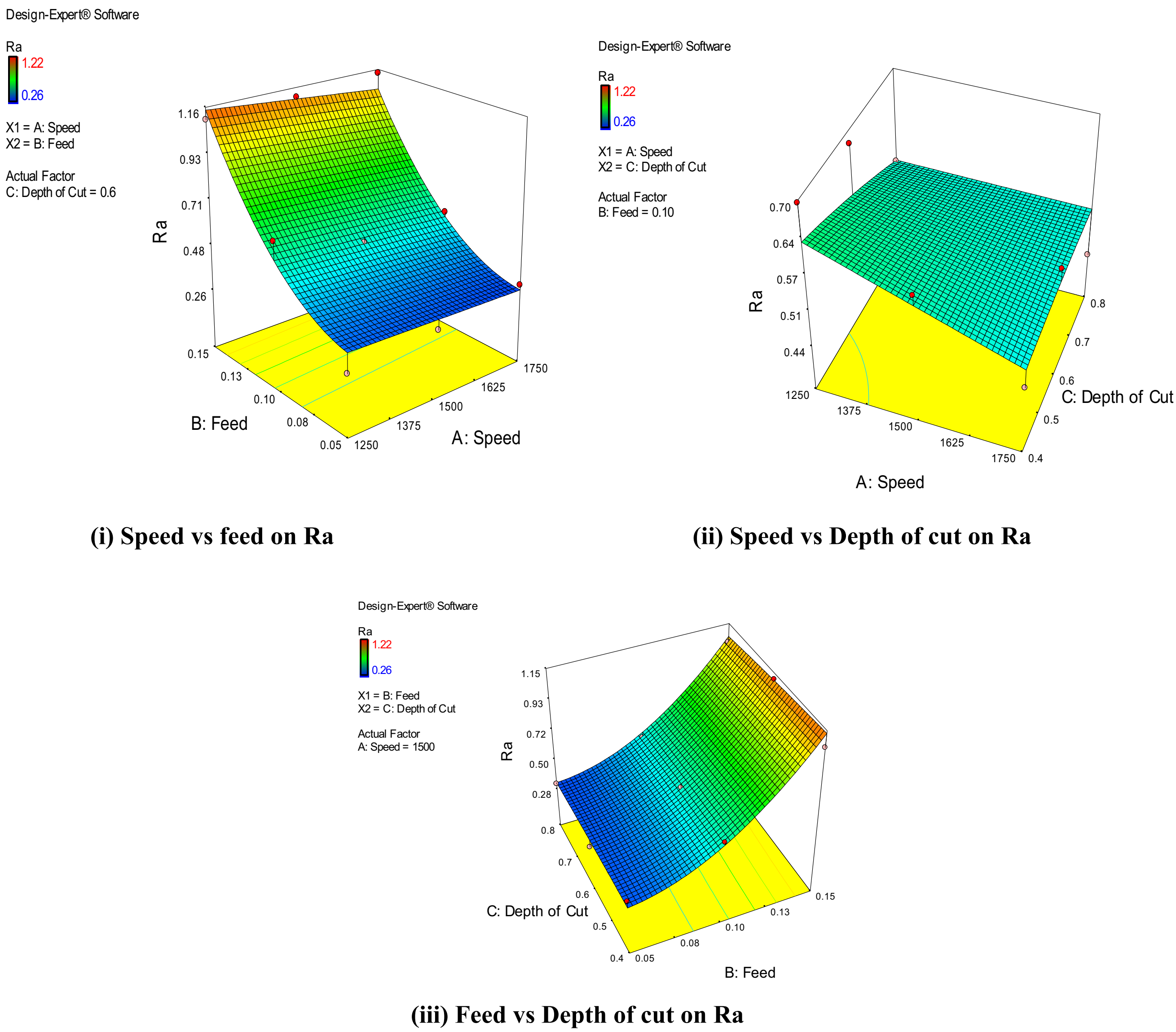


Fig. 8 (i) Speed versus feed on Ra, (ii) speed versus depth of cut on Ra and (iii) feed versus depth of cut on Ra

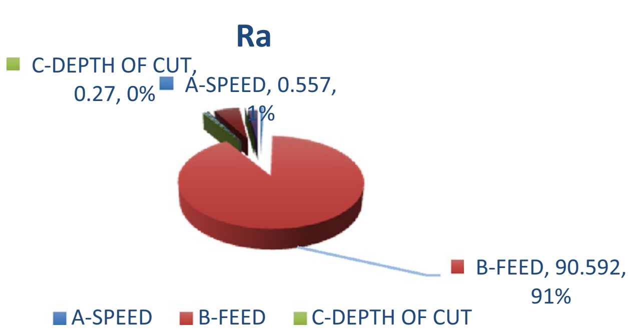


Fig. 9 Contribution plot for Ra for dry condition

at speed 1250 rpm and DOC 0.4 mm. For the figure it is observed that speed of 1250 point is increased and the depth of cut 0.8 to 0.4 m/min is decreased. The Ra is increased at the speed 1250 and depth of cut is decreased at a point 0.8 m/min. It changes in Ra the constant speed at speed increases, Ra also increases. The maximum Ra is achieved at a depth of cut is 0.8 m/min and speed 0.4 mm.

Figure 10(ii) shows effect feed and depth of cut on Ra. From the figure it is revealed that Ra is low at depth of cut is 0.4 mm and feed 0.05 m/min. For the depth of cut point 0.05 mm is increased from 0.05 to 0.15 m/min. The increased in Ra is at the feed 0.05 m/minand depth of cut is 0.4 to 0.8 mm. The changes in Ra is the constant speed at depth of cut increases, Ra also increased. The maximum Ra

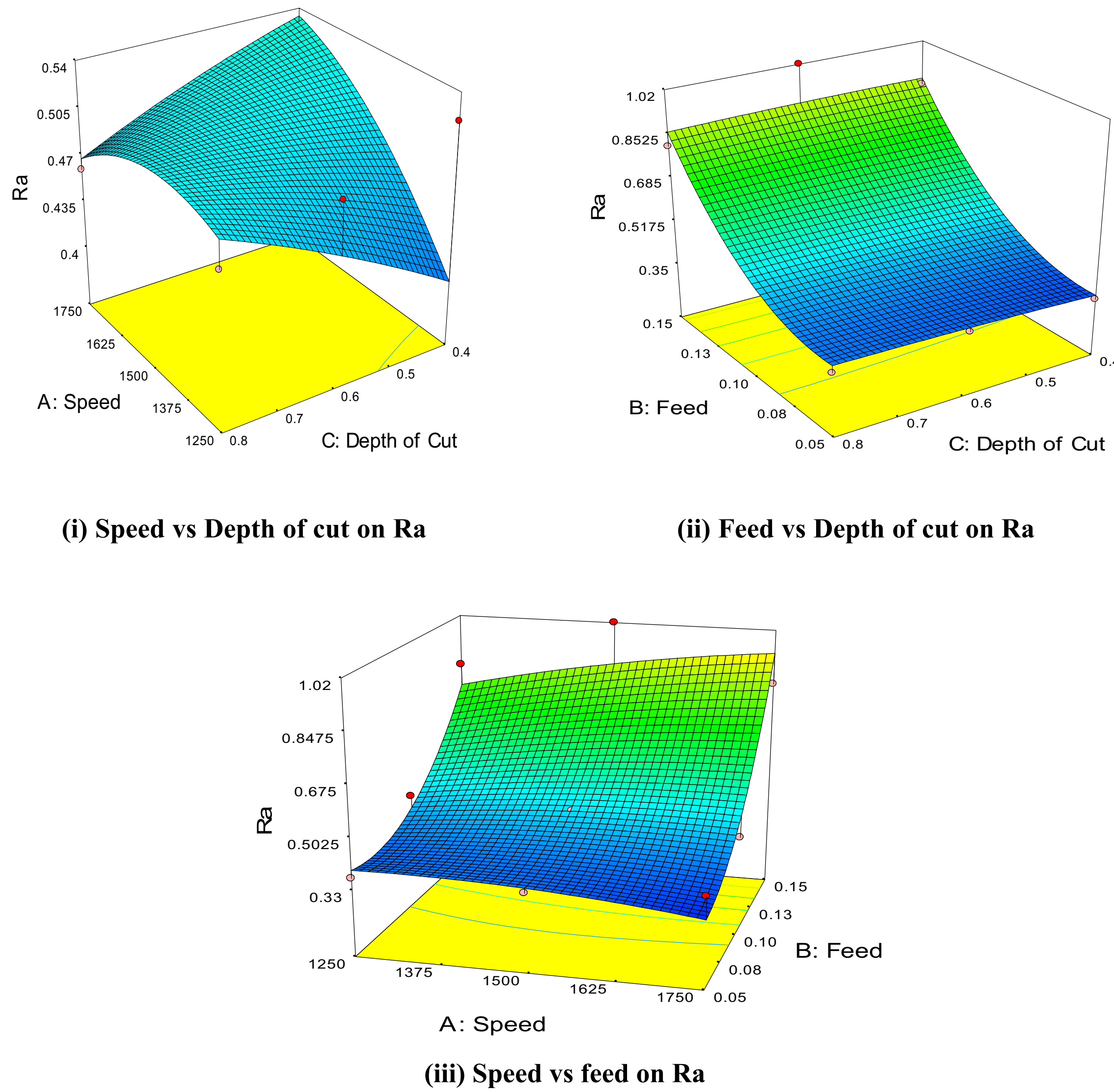
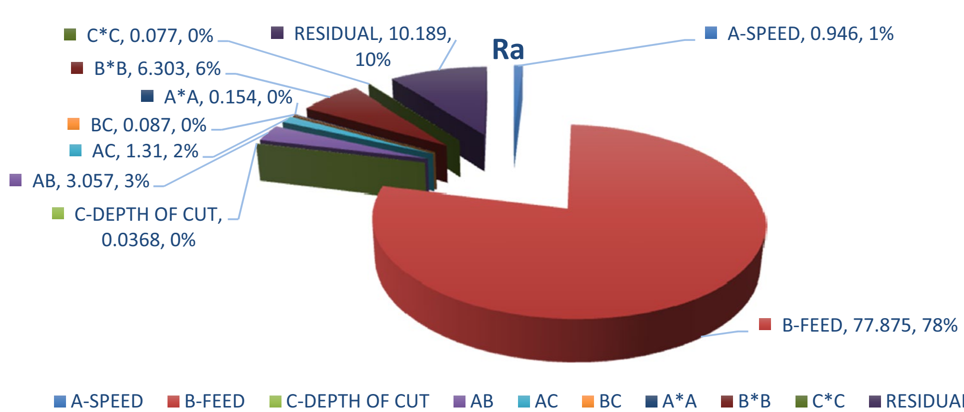


Fig. 10 (i) Speed versus depth of cut on Ra, (ii) feed versus depth of cut on Ra and (iii) speed versus feed on Ra

Fig. 11 Contribution plot for Ra in 0.5% nano lubrication



is achieved at a depth of cut is 0.8 mm and feed is 0.15 m/min.

Figure 10(iii) shows the effect of feed and speed on Ra. From the figure (iii) it is understand that Ra is low at feed rate 0.05 m/min and speed 1250 rpm. For the Fig. 10(iii) it is observed that feed of 0.05 point is increased from 1250 to 1750. The Ra is increased at the speed 1250 and feed is increased at 0.05 to 0.15 m/min. It changes in Ra the constant speed at feed increases, Ra also increases. The maximum Ra is achieved at a feed rate 0.15 m/min and speed 1750 rpm.

The contribution chart Fig. 11 shows the input parameter feed creates major role for the output parameter Ra. It influence around 77% on Ra and follows that depth of cut and speed influence the Ra. The contribution of speed on the Ra is low when compare with depth of and feed. The reason is that, the depth of cut and feed are decides the amount of materials to be removed from the workpiece. When the material removal increases naturally the surface roughness of the workpiece is affected. Hence irrespective of the speed, the depth of cut and feed affecting the roughness of the workpiece [27].

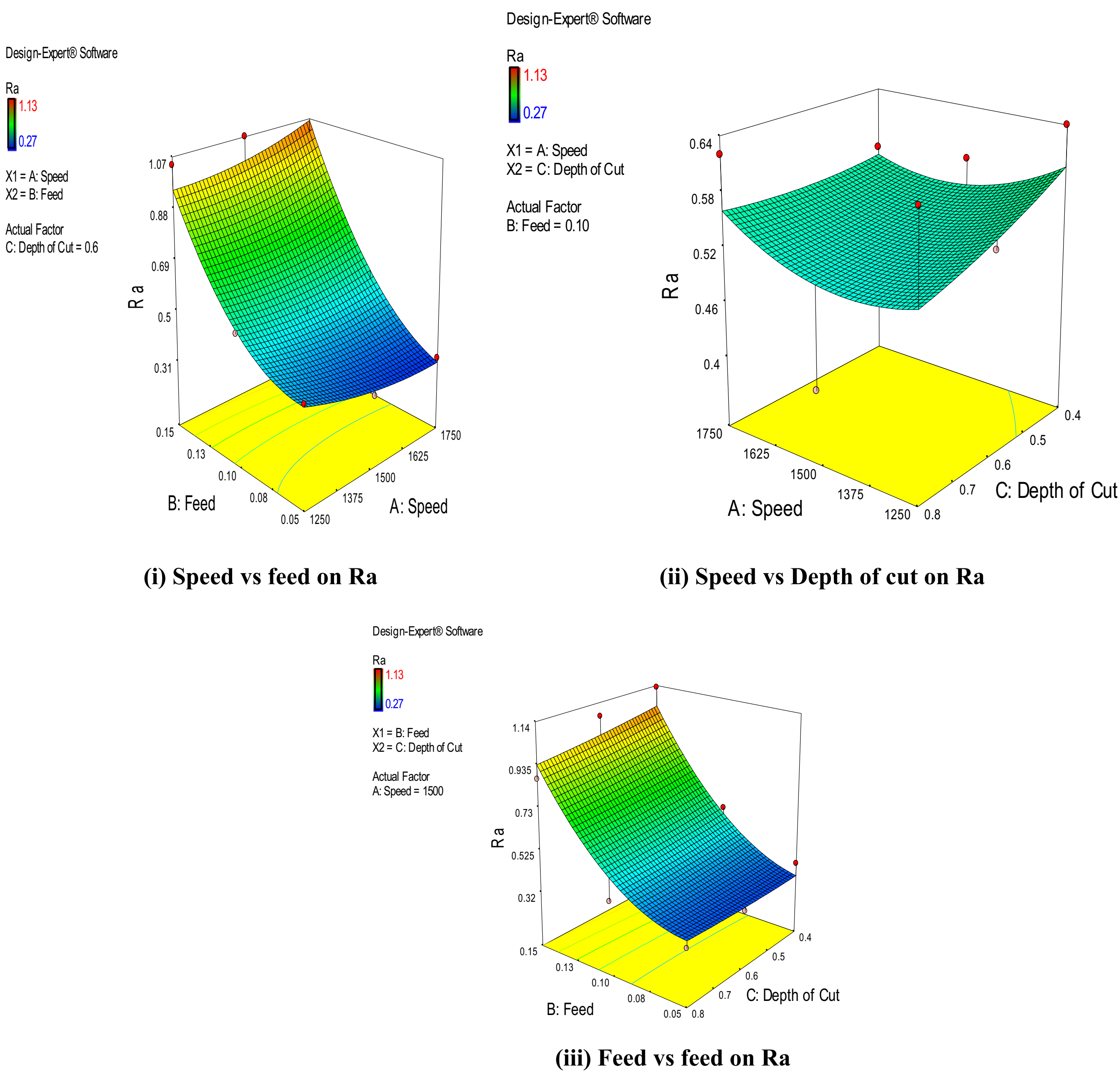


Fig. 12 (i) Speed versus feed on Ra, (ii) speed versus depth of cut on Ra and (iii) feed versus feed on Ra

4.2.3 SR under 1% nano lubrication condition

Regression model for Ra

$$\begin{aligned} \mathrm{Ra} = &+0.52 + 1.667\mathrm{E}{-}003 * \mathrm{A} + 0.32 * \mathrm{B} - 0.019 * \mathrm{C} \\ &+ 0.055 * \mathrm{A} * \mathrm{B} + 0.018 * \mathrm{A} * \mathrm{C} - 0.028 * \mathrm{B} * \mathrm{C} \\ &+ 0.028 * \mathrm{A}^2 + 0.14 * \mathrm{B}^2 + 6.667\mathrm{E}{-}003 * \mathrm{C}^2 \end{aligned} \tag{6}$$

Figure 12(i) shows the effect of speed and depth of cut on Ra. It is revealed that Ra is high at speed 1250 rpm and DOC 0.4 mm. For the Fig. 12(i) it is observed that speed of 1250 point is increased and the depth of cut 0.8 to 0.4 m/min is decreased. The Ra is increased at the speed 1250 and depth of cut is decreased at a point 0.8 m/min. It changes in Ra the constant speed at speed increases, Ra also increases. The maximum Ra is achieved at a depth of cut is 0.8 m/min and speed 0.4 mm.

Figure 12(ii) shows effect feed and depth of cut on Ra. From the figure it is observed that Ra is low at depth of cut is 0.4 mm and feed 0.05 m/min. For the depth of cut point 0.05 mm is increased from 0.05 to 0.15 m/min. The increased in Ra is at the feed 0.05 m/min and depth of cut is 0.4 to 0.8 mm. The changes in Ra is the constant speed at depth of cut increases, Ra also increased. The maximum Ra is achieved at a depth of cut is 0.8 mm and feed is 0.15 m/min.

Figure 12(iii) shows the effect of speed and feed on Ra. From the figure (iii) it is understand that Ra is low at speed 1250 rpm and feed rate 0.05 m/min. For the figure (iii) it is observed that speed of 1250 rpm point is increased from the feed 0.05 to 0.15 m/min. The Ra is increased at the feed 0.05 m/min and speed is increased at 1250 to 1750 rpm. It changes in Ra the constant speed at feed increases, Ra also increases. The maximum Ra is achieved at a speed rate 1750 rpm and feed rate is 0.15 m/min.

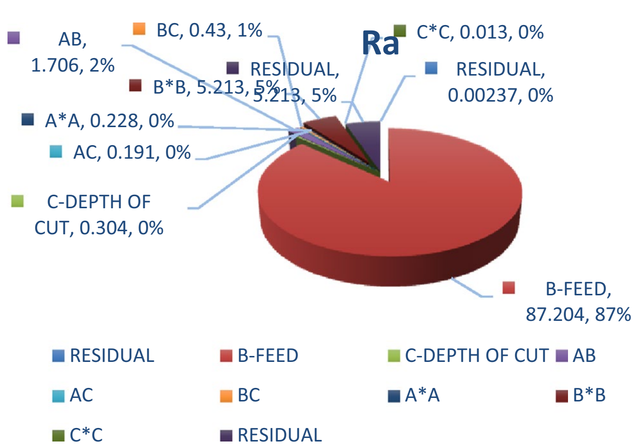


Fig. 13 Contribution plot for Ra in 1%

The contribution chart Fig. 13 shows the input parameter feed creates major role for the output parameter Ra. It influence around 87% on Ra and follows that depth of cut and speed influence the Ra.

5 Multi criteria decision making: TOPOSIS approach

TOPSIS is a technique for the order of preference and it was developed by Hwang and Yoon. It is a multi-criteria optimization technique to appraise the performance of solution. It is simplest one and most reliable. Based on this method, the best substitute one to ideal problem solving. In instant, the positive-superior results are combined of all best values, and the negative-ideal solution consists of all the poorest values manageable of criteria [28].

For solving multi-objective scheduling problems it can be broadly classified into two categories: first category (priori approach) assigns weights to the each objective and the second category (posteriori approach) concerned with finding all efficient solutions, i.e., non-dominated solutions. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by Yang and Tarng [8] is a technique to evaluate the performance of alternatives through the similarity with the ideal solution. The best alternative would be the closest to the positive-ideal solution and farthest from the negative-ideal solution. The positive-ideal solution is one that maximizes the benefit criteria and minimizes the cost criteria. In contrary, the negative-ideal solution maximizes the cost criteria and minimizes the benefit criteria. In summary, the positive-ideal solution is composed of all best values attainable of criteria and the negative-ideal solution consists of all the worst values attainable of criteria. In this work, in order to equal weightage the MRR and SR are given as 0.5. The Topsis technique is applied for dry, 0.5% and 1% of nano fluid lubrication.

6 Conclusion

In this work, the characteristics of machining Al 7075, under dry, 0.5% and 1% of Al_2O_3 Nano lubrication with Minimum Quantity of Lubrication is studied. To study the characteristics, L27 Orthogonal array (full factorial approach) is used and machining is carried out in Siemens CNC lathe. The input parameters of machining are (1) speed ranging from 1250 to 1750 rpm, (2) feed between 0.05 and 1.5 mm and (3) depth of cut varied from 0.4 to 0.8 mm. The output parameters are metal removal rate (MRR) and surface roughness (SR). The regression models developed from ANOVA are significant.

- Under dry condition

  1. The maximum MRR (6.021 cc/min) at the maximum value of speed (1750 rpm), feed (1.5 mm) and depth of cut (0.8 mm). From the contribution plot for achieving maximum MRR the feed contributes 57% followed with the depth of cut 23%.
  2. The minimum value of Surface roughness (0.26 microns) is achieved at the minimum value of speed (1250 rpm), minimum feed (0.05 mm) and depth of cut of (0.6 mm). From the interaction plot it is observed that the better Surface roughness, the contribution of feed is 91% as compared to other input parameters.

- Under 0.5% nano lubrication

  1. The MRR is maximum at 5.92 cc/min is achieved for the similar input parameters like dry condition. From the contribution plot it is inferred that the feed contributes 55% followed with the depth of cut 29%.
  2. The surface roughness (0.27 microns) is attained at the maximum value of speed (1750 rpm), minimum feed of 0.05 mm and minimum depth of cut of 0.4 mm. The interaction plot shows the better Surface roughness, the contribution of feed is 77% as compared to other input parameters.

- Under 1% nano lubrication

  1. The same maximum MRR of 5.92 cc/min is achieved for the similar input parameters like dry condition. From the contribution plot, it is inferred that the feed contributes 59% followed with the depth of cut 28%.
  2. The surface roughness (0.3 microns) is attained at similar to the input parameters of 0.5% nano lubrication condition. The interaction plot shows the better surface roughness, the contribution of feed is 87% as compared to other input parameters.

From the above result, the contribution of feed is most predominant parameters for the achievement of better MRR and surface roughness. It is also concluded that the MRR under 0.5% and 1% of Al_2O_3 Nano lubrication gives almost similar values, whereas for achieving better surface roughness, 1% of Al_2O_3 Nano lubrication gives better result as compared to 0.5% nano lubrication and dry condition. From the TOPSIS with the equal weightage (0.5 each) of MRR and SR, it is observed that the best operating parameters are cutting speed-1750 rpm, cutting feed-0.15 mm and depth of cut-0.8 mm.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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