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Optimisation of turning AISI 1040 steel with extreme pressure additive in vegetable oil based cutting fluids

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ABSTRACT

This paper aims to obtain the optimal combination of machining parameters for multiple performance characteristics in the turning operation by implementing desirability function analysis. Experiments were conducted using machining parameters like different proportions (5%, 10%, and 15%) of extreme pressure additive in three different vegetable oil based cutting fluids (sesame, canola, and coconut oils), cutting speed and feed rate for evaluating the cutting force, cutting tool temperature, tool flank wear, and surface roughness. An orthogonal array (L_{27}) was generated using the Taguchi design to carry out the experiments on AISI 1040 steel. Composite desirability was analysed for identifying the optimal levels of machining parameters. Experimental results revealed that cutting fluid had the most significant effect on cutting force, cutting tool temperature, tool flank wear, and surface roughness. Confirmation test was carried out to validate the results. Experimental results have shown that machining performance can be improved through desirability function analysis.

Keywords: Turning; VBCFs; EP additive; S/N ratio; Taguchi method; desirability function analysis.

INTRODUCTION

Cutting fluids (CFs) are used in metal cutting industries due to their inherent lubrication and cooling properties. Cutting fluids usage reduces cutting forces and vibration, and increases tool life, surface finish, and machining process efficiency. In modern manufacturing industries, synthetic and mineral oil based cutting fluids are extensively used [1]. Many problems such as health and environmental issues are identified with the use of conventional cutting fluids [2-6]. Furthermore, cutting fluids also incur a major portion of the total manufacturing cost. To overcome these problems, researchers are currently exploring various alternatives to petroleum-based metal working fluids. Vegetable oils are effective substitutes for petroleum-based oils because they are biodegradable, environmentally friendly, less toxic, and renewable and possess good lubricity [7, 8]. In general, vegetable oil based cutting fluids (VBCFs) have superior performances to other types of cutting fluids in terms of reduction of cutting forces, tool wear, and surface roughness [7, 9-11]. Additives like sulfur and organosulfur compounds are used in commercial "neat" cutting oils when the sensitivity of the machining operations requires the application of extreme pressure (EP) properties in the fluid. EP additives when added to lubricants tend to reduce the heat due to friction between tool and chip face and by plastic deformation of the metal. In these oils, the additives used are mostly confined to sulfur or sulfurised fats. Sulfur additives are well-known for their anti-wear, anti-oxidation, and strong EP characteristics [12]. According to De Chiffre [13], with the use of cutting fluids, machining performance was improved as shown by the reduction in cutting forces and vibrations, increased tool life, and improved surface finish. De Chiffre [14] conducted a reaming test and evaluated the lubricating efficiency of cutting fluids. In this test tapping torque, feed force, and surface roughness were measured in reaming. In the investigation, technically-pure aluminium was used as the workpiece material while four laboratory water-based cutting fluids, as well as commercial cutting oil, were used as cutting fluids. The results indicated that the lubricants had a significant and similar effect with respect to both tapping and reaming torques. In another study [15], performance of cutting fluids was evaluated through the turning, drilling, reaming, and tapping operations of AISI 316L austenitic steel by measuring the cutting forces, tool life, and dimensional quality. It was found that by using cutting fluid, tool life increased by 177% while thrust force decreased by 7%.

Due to high biodegradability and lower environmental impact, vegetable and fatty oils have retained their importance and are used as metal working lubricants. Emulsions of vegetable oils are prepared by using ionic and non-ionic surfactants [16-19]. As these emulsions act as metal working lubricants, vegetable oil based emulsions are used in the metal working industry as a substitute for petroleum based emulsions [20]. Singh and Gupta [21] developed eco-friendly metal working soluble oils using non-edible oils like rice bran, karanja, and neem oils. These formulations were found to be stable at normal and high temperatures. The results indicated that soluble oil prepared from all the vegetable oils exhibited 90% biodegradability. Better performance was observed for formulations based on neem oil compared to the other two oils. Lovell [22] evaluated the performance of boric acid and canola oil when forming lubricant in a deep drawing operation. It was reported that boric acid and canola oil combination had a steady state friction value at 44% less than the commercial fluid. Cambiella et al. [23] evaluated the performance of several oil-in-water emulsions in machining operations used as lubricating and cooling fluids in EP tests. The EP properties of the oil-in-water emulsions were studied by considering various proportions of three different emulsifiers (anionic, non-ionic, and cationic surfactants). The results indicated that the performance of oil-in-water emulsions was similar to base oils. Xavior and Adithan [24] studied the performance of coconut oil and neat cutting fluids in terms of reduced tool wear and surface roughness during turning of AISI 304 steel with carbide tool. The performance of coconut oil based cutting fluid was better compared to mineral oil based cutting fluid in reducing tool wear and improving surface finish. Bierla et al. [25] conducted physico-chemical analyses in order to evaluate the performance of various sulfur-containing EP additives and understand their action mechanisms in metal cutting. The purpose of this analysis was to detect the nature of additive reaction on the surfaces involved in cutting and correlate them with the milling results in terms of specific cutting energy and tool wear. The results indicated that polysulfide additive exhibited the best efficiency in terms of decreased specific cutting energy and tool wear in the tested milling conditions.

Kuram et al. [26] investigated the effect of EP additive added VBCFs in terms of cutting force, tool life and surface roughness during the end milling of AISI 304 stainless steel. The experiments were conducted with three different VBCFs developed from sunflower oil with 8% EP, canola oil with 8% EP additive, and with a commercial type of semi-synthetic cutting fluid. Cutting fluid was applied to the cutting zone via two nozzles. Results indicated that 8% EP additive included in canola based cutting fluid performed better than others. Najiha et al. [27] applied the genetic algorithm based multi-objective optimisation approach to predict the optimal machining parameters for the end milling process of aluminium alloy 6061 T6 combined with minimum quantity lubrication conditions using water-based TiO_2 nanofluid as the cutting fluid to minimise the surface roughness, maximise the material removal rate, and minimise the flank wear of the cutting tool. Robin and Hariom [28] analysed the effect of machining parameters on surface roughness and material removal rate in a turning operation using the Taguchi method. The conclusions revealed that the feed rate, cutting speed, depth of cut and insert had a great impact on material removal rate and surface roughness. Gokul and Smitha [29] conducted a comparative study of dry and wet machining where rice bran oil and coolant oil were used as the cutting fluids in a CNC lathe for the turning operation on plain carbon steels EN8 and EN9 for surface roughness and tool life. The results indicated that the best cutting conditions were obtained for coolant oil followed by rice bran oil. Padmini et al. [30] experimented with nano cutting fluids formulated from vegetable oils with $nMoS_2$ inclusions for machining AISI 1040 steel through the MQL technique. They inferred that cutting forces, cutting tool temperatures tool wear, and surface roughness were reduced by 37%, 21%, 44% and 39% respectively by using coconut oil with $nMoS_2$ at 0.5% inclusions compared to dry, conventional cutting fluid and pure oil assisted machining. Sahid et al. [31] investigated the performance of coated carbide cutting tool during the end mill of aluminium alloy AA6061-T6 using the minimum quantity lubrication. The results revealed that minimum quantity lubrication technique applied to the machining of aluminium alloys provided economic advantages in terms of reduced machining costs and better machinability. An experimental setup was realised by Visconti et al. [32] to carry out test campaigns in order to analyse and compare the spray injections of different fuel typologies. The results showed higher penetration values for biodiesel fuels due to their viscosity and drops in superficial tension, which facilitated a deeper penetration compared to those obtained with conventional diesel fuels. Hanief and Wani [33] investigated the influence of cutting speed, feed rate and depth of cut on the surface roughness during the turning of red brass using ANOVA. It was concluded that the feed rate was the most significant factor influencing the surface roughness, followed by the depth of cut and cutting speed. From the literature, it was observed that investigations related to VBCFs have shown better performance compared to conventional CFs. Addition of EP additive to cutting fluids enhanced their performance due to the favourable properties of EP additives along with vegetable oils. Also, it was observed that better results were achieved with 8% EP additive. However, results may vary with base oil and EP additive. Nevertheless, combination of different vegetable oils with addition of EP additive performance and its optimisation in machining was seldom found. Owing to this reason, coconut oil, canola oil, and sesame oil were used as lubricants in the present work. These vegetable oils with addition of 5, 10 and 15 % EP additives in the cutting fluid were used in the machining operation and the optimum conditions for better performance were investigated. Multi response optimisation problem was converted into an equivalent single response optimisation problem using desirability function analysis.

METHODS AND MATERIALS

All the machining experiments were conducted on PSG-124 lathe with coated carbide tool (CNMG120408NC6110) in turning AISI 1040 steel workpiece with hardness of 30±2 HRC (Rockwell Hardness). Figure 1 shows the experimental setup for the turning process. Chemical composition of AISI 1040 workpiece material is given in Table 1. The experimental details are presented in Table 2. Sulfur based EP additive (HiTEC343) was used to prepare VBCFs because it is less viscous, possesses good solubility in water, and has high lubricating ability [34]. Cutting fluid was prepared by adding EP additive to canola, coconut, and sesame oils at proportions of 5%, 10%, and 15% by weight, respectively. Initially, emulsifier and vegetable oil were mixed in the ratio of 15% and 85% by weight, respectively. Then, a premeasured quantity of EP additive was taken in a beaker while the required quantities of emulsifier and vegetable oil mixture were added by manually mixing both to obtain a homogenous solution. Finally, VBCF was prepared by adding water to the mixture in oil at a 9:100 ratio. Cutting fluid was supplied at the rate of 3.5 lit/min at the machining zone.

Figure 1. Experimental set up.

Table 1. Chemical composition of AISI 1040 steel by wt. % [26].

C	Si	Mn	S	P	Fe
0.36-0.45	0.2-0.3	0.60-1.00	0.025	0.015	Balance

Machining experiments were conducted at varying cutting conditions with nine different VBCFs formulated from canola, coconut, and sesame oils (including 5%, 10% and 15% of EP additives) for recording responses such as cutting force (F_c), cutting tool temperature (T), tool flank wear (V_b) and surface roughness (R_a). The cutting forces were tracked online using the DynoWare software by fixing Kistler 9272 dynamometer to the lathe tool post. Cutting temperatures were sensed online by an embedded thermocouple (K-type) calibrated in the range of 0 °C – 1000 °C. GX51 optical microscope offline was employed for measuring tool flank wear. For measuring surface roughness offline, a Surf test with SJ-301, MITUTOYO, diamond stylus with tip radius of 5 µm was employed. Response value was considered by calculating the average of measurements taken at three different locations.

Table 2. Experimental details.

Workpiece Material:	AISI 1040 (C: 0.36–0.45%, Mn: 0.6–1%, Si: 0.2–0.3%, S: 0.025%, P: 0.015%)
Hardness	30 ±2 HRC
Tool holder	PSRNR12125F09
Cutting tool (insert)	CNMG120408NC6110 coated carbide (TiCN/Al_2O_3 coating)
Cutting speed	60, 80 and 100 m/min
Feed rate	0.14, 0.17 and 0.20 mm/rev
Depth of cut	0.5 mm (constant)
Cutting fluids	Coconut, canola, and sesame based cutting
% EP additive inclusion	5, 10, and 15

In this study, type of cutting fluid, proportion of EP additive, and cutting speed and feed were considered as input parameters. The four factors with different levels are presented in Table 3. The prepared CFs were notated as sesame oil based cutting fluid (SCF), canola oil based cutting fluid (CNCF), and coconut oil based cutting fluid (CCF).

Table 3. Levels of machining parameters.

Parameters	Symbol	Unit	Level	Level	Level
Cutting fluid	*CF*	--	SCF	CNCF	CCF
EP additive	*EP*	%	5	10	15
Cutting speed	*V*	m/min	60	80	100
Feed	*f*	mm/rev	0.14	0.17	0.20

Taguchi's L_{27} orthogonal array shown in Table 4 was utilised for the experimental design. MINITAB version 14 was used for the design of experiments. The four factors namely, type of vegetable based cutting fluid, proportion of EP additive, cutting speed and feed were considered in the present analysis. The influence of these factors at various levels on F_c, T, V_b, and R_a was examined by applying DFA. Optimal value for each machining parameter was obtained by analysing the composite desirability. ANOVA was carried out to identify the most influencing factors for F_c, T, V_b, and R_a in turning AISI 1040 steel.

Desirability Function Analysis

Desirability function analysis (DFA) is one of the most widely used methods in the industry for the optimisation of multi-response characteristics. DFA was used to convert multi-response characteristics into single-response characteristics. Optimisation steps using DFA in the Taguchi method are discussed in this section:

Table 4. Orthogonal array (L_{27}) of experiments and measurements.

Trial No.	*CF*	EP	*V*	*f*	F_c	*T*	V_b	R_a
1	SCF	5	60	0.14	101.09	29	91.8	4.14
2	SCF	5	80	0.17	157.98	33	130.5	5.16
3	SCF	5	10	0.20	123.25	42	239.1	4.53
4	SCF	10	60	0.17	91.820	29	87.2	3.91
5	SCF	10	80	0.20	156.16	34	209.5	6.13
6	SCF	10	10	0.14	58.419	38	105.0	3.80
7	SCF	15	60	0.20	127.30	32	155.6	5.22
8	SCF	15	80	0.14	162.69	32	125.6	5.35
9	SCF	15	10	0.17	125.80	41	154.7	4.54
10	CNCF	5	60	0.17	90.387	29	88.45	3.69
11	CNCF	5	80	0.20	156.96	33	162.1	5.54
12	CNCF	5	10	0.14	62.272	38	92.14	3.42
13	CNCF	10	60	0.20	90.026	29	99.87	3.94
14	CNCF	10	80	0.14	89.611	29	77.64	3.92
15	CNCF	10	10	0.17	68.397	39	102.2	3.26
16	CNCF	15	60	0.14	98.055	29	84.45	3.86
17	CNCF	15	80	0.17	124.48	33	119.0	4.81
18	CNCF	15	10	0.20	95.137	42	185.1	4.35
19	CCF	5	60	0.20	88.096	29	84.6	3.63
20	CCF	5	80	0.14	82.169	28	61.65	3.44
21	CCF	5	10	0.17	60.319	38	91.45	2.94
22	CCF	10	60	0.14	66.250	26	53.52	2.63
23	CCF	10	80	0.17	79.014	29	74.52	3.50
24	CCF	10	10	0.20	61.130	39	83.60	3.20
25	CCF	15	60	0.17	86.974	29	87.56	3.45
26	CCF	15	80	0.20	142.32	32	98.33	4.96
27	CCF	15	10	0.14	57.887	39	73.45	3.06

CF: cutting fluid; *EP*: EP additive in %; *V*: cutting speed in m/min; *f*: feed in mm/rev; F_c: cutting force in N; *T*: cutting tool temperature in ^{0}C; V_b: tool flank wear in µm; R_a: surface roughness in µm.

Step 1: Evaluation of the individual desirability index (d_i):

The individual desirability index (d_i) was calculated for the corresponding responses using the formula proposed by Derringer and Suich [35]. There were three forms of desirability functions according to the response characteristics.

(a) The nominal-the-best: The desirability function of the nominal-the-best can be written as shown in Eq. (1). The value of $\hat{y}$ is required to achieve a particular target 'T'. When $\hat{y}$ equals to 'T', the desirability value equals to 1; if the departure of $\hat{y}$ excesses a particular range from the target, the desirability value equals to '0' and, such situation represents the worst case.

$$d_i = \begin{cases} \left(\dfrac{\hat{y} - y_{\min}}{T - y_{\min}} \right)^s, & y_{\min} \le \hat{y} \le T, s \ge 0 \\ \left(\dfrac{\hat{y} - y_{\min}}{T - y_{\min}} \right)^t, & T \le y \le \hat{y}_{\max}, t \ge 0 \\ 0, & otherwise \end{cases} \qquad (1)$$

where, the $y_{\max}$ and $y_{\min}$ represent the upper/lower tolerance limits of $\hat{y}$ and, $'s'$ and $'t'$ represent the weights.

(b) The smaller-the-better: The desirability function of the smaller-the-better can be written as shown in Eq. (2). The value of $\hat{y}$ is expressed to be the smaller-the-better. When $\hat{y}$ is less than a particular criteria value, the desirability value equals to 1; if $\hat{y}$ excesses a particular criteria value, the desirability value equals to ‘0’.

$$d_i = \begin{cases} 1, & \hat{y} \le y_{\min} \\ \left(\dfrac{\hat{y} - y_{\max}}{y_{\min} - y_{\max}} \right), & y_{\min} \le \hat{y} \le y_{\max}, r \ge 0 \\ 0, & y \ge \hat{y}_{\max} \end{cases} \qquad (2)$$

where $y_{\min}$ represents the lower tolerance limit of $\hat{y}$

$y_{\max}$ represents the upper tolerance limit of $\hat{y}$ and $'r'$ represents the weight

$'s'$, $'t'$ and $'r'$. Term (1) to term (2) indicate the weights and they are defined according to the requirement of the user.

When the corresponding response is expected to be closer to the target, the weight can be set to the larger value; otherwise, the weight can be set to the smaller value.

(c) The larger-the better: The desirability function of the larger-the-better form is shown in Eq. (3). The value of $\hat{y}$ is expected to be the larger-the-better. When $\hat{y}$ exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to ‘1’; if $\hat{y}$ is less than a particular criteria value, which is unacceptable, the desirability value equals to ‘0’.

$$d_i = \begin{cases} 0, & \hat{y} \le y_{\min} \\ \left(\dfrac{\hat{y} - y_{\min}}{y_{\max} - y_{\min}} \right), & y_{\min} \le \hat{y} \le y_{\max}, r \ge 0 \\ 1, & \hat{y} \ge y_{\max} \end{cases} \qquad (3)$$

where the $y_{\min}$ represents the lower tolerance limit of $\hat{y}$; $y_{\max}$ represents the upper tolerance limit of $\hat{y}$, and $'r'$ represents the weight.

Step 2: Computation of composite desirability (d_G)
The individual desirability index of all the responses can be combined to form a single value called composite desirability (d_G) by using the following Eq. (4):

$$d_G = \sqrt[w]{\left(d_1^{w_1} * d_2^{w_2} * \ldots\ldots\ldots\ldots\ldots * d_i^{w_i}\right)} \tag{4}$$

where,

d_i is the individual desirability of the property Y_i,

w_i is the weight of the property "Y_i" in the composite desirability, and

w is the sum of the individual weights.

Step 3: Determination of optimal parameter and its level combination
The higher the composite desirability value, the better the product quality. Therefore, on the basis of the composite desirability (d_G), the parameter effect and optimum level for each controllable parameter are estimated.

Step 4: ANOVA
ANOVA establishes the relative significance of parameters in terms of their percentage contribution. The calculated total sum of square values was used to measure the relative influence of the parameters.

Step 5: Calculate the predicted optimum condition
Once the optimum level of the design parameters has been selected, the final step was to predict and verify the quality characteristics using the optimal level of the design parameters.

RESULTS AND DISCUSSION

The individual desirability (d_i) was calculated for all the responses depending upon the type of quality characteristics. Since all the responses possessed minimisation objective, the equation corresponding to the smaller-the-better type was selected. The computed individual desirability values for the quality characteristics using Eq. (2) are shown in Table 5. The composite desirability values (d_G) were calculated using Eq. (4). Equal weightage was given to all responses $(w_1 = w_2 = w_3 = w_4 = 1 \text{ and } w = 4)$. Finally, these values were considered for optimising the multi response parameter design problem. The results are given in Table 5. From the value of composite desirability (Table 5), the parameter effect and optimal level were estimated. The results are presented in Table 6. Considering the maximisation of composite desirability value (Table 6 and Figure 2), the optimal parameter condition was obtained as $CF_3\, EP_2\, V_1\, f_1$. The reason for the decrease in cutting force with 10% of EP additive was due to the formation of lead sulfide as EP additive which reacted with the surface and eased up plastic deformation [36]. The reduction in cutting tool temperature was due to the better viscosity property of coconut oil based cutting fluid. Fatty acid chain in vegetable oils provided a desirable boundary lubrication and reduced friction which resulted in reduced tool flank wear. Cooling and lubricating effects of EP additive were also added to vegetable oil. Under high cutting temperatures, EP additive created a thin lubricating film on the tool and workpiece. When the mixture of EP additive and vegetable oil flowed at the interface, it decreased plastic contacts which resulted in reduction of tool flank wear [25]. This was more effective with 10% EP additive in coconut oil for reduction of tool flank wear. The reduction in tool flank wear was due to the better viscosity property of coconut oil based cutting fluid which reduced friction at tool-chip and tool-workpiece interfaces [37]. The reason behind the reduction in surface roughness was the low viscosity of coconut oil based cutting fluid compared to canola and sesame oil based cutting fluids which reduced friction between tool-chip and tool-workpiece interfaces.

Table 5. Individual desirability (d_i) and composite desirability (d_G).

Trial No.	Individual Desirability (d_i)				Composite desirability (d_G)
	F_c	T	V_b	R_a	
1	0.5877	0.8125	0.7938	0.5686	0.6814
2	0.045	0.5625	0.5854	0.2771	0.2531
3	0.3763	0.0000	0.0000	0.4571	0.0000
4	0.6762	0.8125	0.8186	0.6343	0.7308
5	0.0623	0.5000	0.1597	0.0000	0.0000
6	0.9949	0.2500	0.7224	0.6657	0.5881
7	0.3377	0.6250	0.4497	0.26	0.3963
8	0.0000	0.6250	0.6118	0.2229	0.0000
9	0.3520	0.0625	0.4549	0.4543	0.2597
10	0.6899	0.8125	0.8119	0.6971	0.7505
11	0.0547	0.5625	0.4151	0.1686	0.2154
12	0.9582	0.2500	0.7920	0.7743	0.6191
13	0.6933	0.8125	0.7504	0.6257	0.7171
14	0.6973	0.8125	0.8701	0.6314	0.7469
15	0.8997	0.1875	0.7376	0.8200	0.5652
16	0.6167	0.8125	0.8334	0.6486	0.7214
17	0.3645	0.5625	0.6469	0.3771	0.4729
18	0.6446	0.0000	0.2911	0.5086	0.0000
19	0.7118	0.8125	0.8326	0.7143	0.7658
20	0.7683	0.8750	0.9562	0.7686	0.8384
21	0.9768	0.2500	0.7957	0.9114	0.6487
22	0.9202	1.0000	1.0000	1.0000	0.9794
23	0.7984	0.8125	0.8869	0.7514	0.8109
24	0.9691	0.1875	0.838	0.8371	0.5975
25	0.7225	0.8125	0.8167	0.7657	0.7784
26	0.1943	0.6250	0.7586	0.3343	0.4189
27	1.0000	0.1875	0.8927	0.8771	0.6190

Using the composite desirability value, ANOVA was formulated for identifying the significant parameters. The results of ANOVA are given in Table 7. From ANOVA, it was evident that the type of cutting fluid contributed about 32.31% and played a dominant role when turning AISI 1040 steel followed by cutting speed (24.85%), feed rate (20.72%) and % EP additive (10.99%). The error of contribution was 11.13%. The confirmation experiment was conducted at optimum settings to verify the quality characteristics for turning AISI 1040 steel as recommended by the investigation. The response values by the confirmation experiment at the optimal settings were $F_c = 66.2509$ N, T = 26 °C, $V_b = 53.52$ µm, and $R_a = 2.63$ µm. Thus, the composite desirability value (μ_{cd}) was found to be 0.9794. This result is within the 95% confidence interval of the predicted optimum condition.

Table 6. Parameter effects for composite desirability (d_G).

Levels	Parameters			
	CF	*EP*	*V*	*f*
1	0.3233	0.5303	**0.7246**	**0.6437**
2	0.5343	**0.6373**	0.4174	0.5856
3	**0.7174**	0.4074	0.4330	0.3457
Delta	0.3942	0.2299	0.3072	0.2981
Rank	1	4	2	3
Optimum	CF_3	EP_2	V_1	f_1

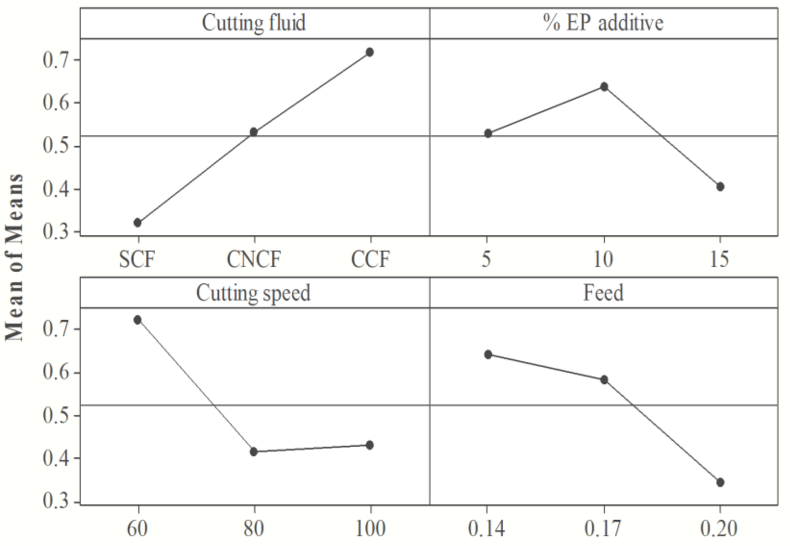

Figure 2. Effect of process parameters on composite desirability.

Table 7. ANOVA for composite desirability.

Parameters	Degrees of freedom	Sum of square	Mean square	F – Test	% contribution
Cutting fluid	2	0.700	0.3501	26.12	32.31
% EP additive	2	0.238	0.1191	8.89	10.99
Cutting speed	2	0.538	0.2694	20.10	24.85
Feed rate	2	0.449	0.2246	16.76	20.72
Error	18	0.241	0.0134		11.13
Total	26	2.168			100.00

CONCLUSIONS

In this study, cutting force, cutting tool temperature, tool flank wear, and surface roughness obtained in turning AISI 1040 steel from the Taguchi's experimental design were reduced from multiple performance characteristics to a single performance characteristic using Desirability Function Analysis. During turning, varying cutting conditions (cutting speed and feed rate), and VBCFs with 5%, 10%, and 15% EP additives were applied. The level of influence for machining performance on multiple performance characteristics was determined by analysing composite desirability. Based on the experimental results, the following conclusions were drawn.

i) The optimum parameter setting ($CF_3\ EP_2\ V_1\ f_1$) resulted in lower cutting force, cutting tool temperature, tool flank wear, and improved surface finish.
ii) Desirability Function Analysis has revealed that cutting fluid was considered as an important parameter in turning, along with cutting speed, feed, and percentage of EP additive which influenced multiple performance characteristics.
iii) Cutting fluid was influential to a greater extent by 32.31%, followed by cutting speed (24.85%), feed (20.72%) and % EP additive (10.99%) on machining performance. The error of contribution was 11.13%.
iv) The present work provides a basis for further research to be carried out on cutting fluids with different vegetable oil based cutting fluids, including different types of EP additives at varying proportions for improving machining performance.

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