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Original Article

Investigation on Effects of Biolubricants Based Hybrid Nanofluids on Turning of AISI 1040 Steel Using Minimum Quantity Lubrication

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Abstract *- Machining operation is one of the most cardinal processes employed in the production industry. The workpiece condition was decided during the machining operation at the cutting zone temperature. The cutting lubricants were widely used in the cutting operation it minimize the temperature and maintain the grade of the workpiece. During machining, ecology and health workers are important factors to recognize no damaging effect on the environment-sustainable replacement to traditional cutting fluids. The research work studied that using biolubricants-based hybrid nano lubricants were used in the turning of AISI 1040 medium carbon steel with an inserts carbide tool. Palm oil as base fluid and SiC and* TiO_2 *nanoparticle suspension is used with minimum quantity lubrication. The performance parameter such as surface roughness, material removal rate, and temperature was recorded. It shows that performance parameter was compared with individual and hybrid modes.*

Keywords *- MQL, Biolubricants, PCA, Turning, MRR, Surface roughness.*

1. Introduction

Biodegradable hybrid nano lubrication is essential for machining industries. The mechanical, physical, and chemical properties of titanium alloy are widely used in industrial applications such as automobile, aviation, defense and power generation. Titanium alloy is are difficult cut material due to its high temperature in machining potation. To using nanomaterials improves the better capacity of cooling in MQL [1]. One way to enhance machining performance without adding more fluid is to use a minimal quantity of lubricant. The minimum quantity of lubrication and dry machining is being used in the machining of Inconel 625 to generate hybrid nanomaterial. To enhance the surface roughness, minimum temperature, less cutting force [2]. The ideal alternative for flooding the cooling form and minimizing the volume of machining fluid is minimum quantity lubrication or MQL. The MQL has a much lower heat capacity when compared to conventional flood coolant. Gamma nanoparticles are used to satisfy the cooling capacity of aluminum oxide (Al_2O_3) and minimize tool wear when cutting Austempered Ductile Iron (ADI). This process yielded the best tool in life [3].

The removal of material is an often employed turning operation in businesses, and because it involves significant cutting force, it develops to increase heat. It is challenging to produce low tool wear and great surface quality because of the high heat generation procedure. Two of the greatest vegetable oils for cutting fluids are coconut and soybean oils. In order to produce a better outcome, boric acid is combined with both vegetable oils and MQL [4]. One of the greatest ways to use one or more nanofluids is through minimum quantity lubrication; researchers have added three distinct nanoparticles (Al_2O_3, MoS_2, and rutile-TiO_2) to base fluids such as vegetable oils (canola and olive oils). The AL_2O_3 has a good surface finish is occurs. Whereas the MoS_2 are used to less tool wear, the results of MQCL are better in turning [5]. To avoid environmental pollution in the machining process, use the eco-friendly machining process. Because of the ecofriendly machining process is less cost, as well as less hazardous to humans and also to the environment. In general, cutting fluids is mostly a high cost, transportation cost, and self-toxic in nature. The disposal of used fluids is a major problem hazardous to humans. In this view there, is solution to these problems is Minimum Quantity Lubrication (MQL) used in machining operations. Al_2O_3 nano particles and vegetable oils are used MQL with different volume fraction [6]. AISI 1040 steel is turned using an insert carbide tool and a suspension of nanosolid lubricants. The Boric acid is associated with the solid lubricant with a particle size of 50 nm, the coconut and SAE – 40 oils are used as base fluids [7].

Numerous lubrication with cooling systems have already been put in place to reduce dangerous temperatures and environments and enhance titanium alloy machining.

Cryogenic cooling with (MQL) based on the nano additives are the two main types of cooling and lubrication systems. Comparing the cryogenic system to MQL procedures, the cutting temperature is reduced by 11.2%. The top two distinct sustainable cooling systems are realized in this view [8]. There is a lot of focus on hard cutting as an alternate lubricant for several types of typical machining processes. Because of the intricate part shapes that prevent cutting fluids, the high surface polish, and the low tool investment. Conventional fluids produce a lot of heat in the cutting area [9]. The nanofluid MQL with vegetable based oil are cylindrical machining of AISI 1045 steel, are the various lubrication/ cooling conditions such as dry machining, MQL [10]. Lubricating oil/ coolant plays a vital role in machining operations, high-rate production, tool life, and finishing work. To reduce the environmental hazards as well as to minimize the production cost. The silver nanoparticles are synthesized and dispersed with lubricating oil in the view the results show that reduction of tool temperature, and a good surface finish [11]. Using the cutting fluids and monotype nanoparticles in the cutting process is the focus of numerous researchers. When machining materials such as Multi Walled Carbon Nanotubes (MWCNTs) with varying volume percentages, a hybrid nanofluid is employed. When MQL-based turning procedures were applied to AISI 304 steel, it showed that the hybrid nano coolants carried out performed significantly better as a coolant [12]. The majority of Inconel 718's applications are in the industrial sector, mostly in the aerospace industry. Flood cooling is a popular application; however, machinability issues can arise. Using MQL data, it was found that Multi-Wall Carbon Nanotubes (MWCNTs) offered superior enhancements compared to Aluminum Oxide (Al_2O_3) nanoparticles [13].

The effectiveness of oil-based vegetable nanofluids. AISI 1040 steel is turned while using Minimum Quantity Lubricant (MQL). Different samples are mixed with Molybdenum Disulphide ($nMoS_2$) nanoparticles to create synthetic base fluids like Canola (CAN), Sesame (SS), and Coconut (CC). The purpose of using these fluids is to reduce surface roughness, tool wear, cutting forces, and temperatures [14]. The two distinct nanofluids are created by combining molybdenum disulphide and alumina and then twisting AISI304 stainless steel using the resultant hybrid nanofluid [15].

The MQL is one of the efficient methods as compared to flood cooling because MQL is to control the temperature during the machining. The working and development of MQL are so much more complicated, but the machining results were better [16]. the most crucial element in the creation of hybrid nanofluids is the improvement of tribological characteristics with the addition of alumina and Molybdenum Disulphide (MoS_2) nanoparticles to oil-water produced with a volumetric ratio of 10:29. The hybrid nano lubricant produced superior outcomes. AISI 304 steel turning has been carried out to calculate the improvement of various lubricants utilizing cutting operations related to the Minimum Quantity Lubrication (MQL) technique [17]. The MWCNT nano particle-based nano lubricants have better results than that researchers have looked at jojoba, a vegetable oil that has been mixed with Molybdenum Disulfide Nanoparticles (nMoS2), which are hard to spin and are linked to Minimal Quantity Lubrication (MQL). The superior performance of jojoba oil can be assigned and increased thermal conductivity, stability, and high viscosity index. The view indicates reduced tool wear, better surface smoothness, and the lowest cutting force when using jojoba oil combined with $nMoS_2$ (0.1%) [21]. The tool wear of conventional fluid is using turning of EN 31 steel [18]. By using a variation of GO nanoparticle, the results show that on turning Ti-6A1-4 V was less tool wear than that of conventional coolants [22]. The addition of graphene oxide nanosheet produced positive effects on coolant lubricating processes. It demonstrates that crater and flank wear was more important, and morphological features demonstrate the decrease in temperature and friction force that occurred during the application of grapheme oxide nanosheet [23].

The effects of hybrid nanofluids based on biolubricants on the turning of AISI 1040 medium carbon steel using minimum quantity lubrication were investigated in the current study. According to the view, palm oil, Silicon Carbide (SiC), and Titanium Dioxide (TiO_2) nanoparticle additions are utilized with the biodegradable fluid. The two-step process prepared the hybrid nano fluid's physical and thermal properties. Minimum Quantity Lubrication (MQL) is related to prepared coolants and lubricants; when using AISI 1040 steel in MQL, coolant combinations such as hybrid mode and individual mode are employed. Reducing cutting temperature, surface roughness, tool wear, and Material Removal Rate (MRR) in order to improve machining performance. This effort aims to investigate the impact of machining performance. AISI 1040 steel is used in many different applications, such as cold-headed components, couplings, and crankshafts.

2. Material and Method

2.1. Preparation of Biodegradable Hybrid Nanofluid

In this work, a biodegradable hybrid nanofluid is prepared using nanoparticles of Silicon Carbide (SiC) and Titanium Dioxide (TiO_2), with diameters of 50 nm and 20 nm, respectively. Sodium Dodecyl Sulfate (SDS) is employed as a surfactant, and palm oil is the base lubricant using the preparation of a biodegradable hybrid nanofluid. The nano-cutting fluids were created by mixing nanoparticles like SiC and TiO_2 with base lubricants like palm oil. The concentration of these individual and hybrid modes was created using palm oil as the base lubricants, with SiC + palm oil at a volume concentration of 1,2,3%, TiO_2 + palm oil at a concentration of 1,2,3%, and SiC + TiO_2 + palm oil at a concentration of 1,2,3%. The preparation process was done in two steps using a magnetic stirrer.

Fig. 1 Prepared sample of palm oil and nanomaterial

The biodegradable hybrid nanofluid sample that was created by rotating AISI 1040 steel with minimal lubricant quantity is depicted in Figure 1. Each sample's physical and thermal characteristics, including its viscosity, flash point, and thermal conductivity, are determined.

The stability of biodegradable hybrid nanofluids is the most crucial component of the fluid. To determine the stability of hybrid nanofluid using the Zeta potential analysis. The results indicate that when palm oil is mixed with a suspension of SiC and TiO_2 nanoparticles, hybrid nanofluids with the same volume fraction (1%, 2%, and 3%) are stable. The stability of (SiC+ TiO_2 + palm oil) is higher than that of nanofluids of SiC+ and TiO_2+ palm oil.

Furthermore, a study on thermal conductivity showed that, in comparison to the nanofluids SiC + Palm oil and TiO_2 + Palm oil, the biodegradable hybrid nanofluids SiC + TiO_2 + Palm oil had a better thermal conductivity if the base lubricants were used in palm oil also has a larger thermal concavity. At 1%, 2%, and 3%, the maximum conductivity ratio of biodegradable hybrid nanofluids (SiC+TiO_2+ Palm Oil) is almost 70%. It currently shows a notable rise in palm oil at a modest volume proportion of 1%. After sonication or aggregation of hybrid nanofluids, the volume concentration of hybrid nanoparticles is evidently raised.

3. Experimental Setup

Figure 2 shows the development of the MQL setup using cutting operation, the main parts of setup such as the spry gun, nozzle, compressor, pressure gauge, valve etc. The various combinations of nanofluids are used in experiments. The Fanuc series Oi Mate -TC CNC machine was used in the turning operation, as shown in Figures 3 and 4. It also shows that (SiC+ TiO_2 + palm oil) had greater stability when compared to nanofluids of SiC+ and TiO_2+ palm oil. Additionally, studies on thermal conductivity showed that the biodegradable hybrid nanofluids SiC + TiO_2 + Palm oil had a greater thermal conductivity than the nanofluids SiC + TiO_2 + Palm oil.

Additionally, the palm oil has a larger thermal expansion. For biodegradable hybrid nanofluids (SiC+TiO2+ Palm Oil), the maximum conductivity ratio is approximately 70% at 1%, 2%, and 3%. As of right present, it shows a notable rise in palm oil at a meager 1% volume proportion. Sonication or aggregation of hybrid nanofluids definitely increases the volume concentration of hybrid nanoparticles.

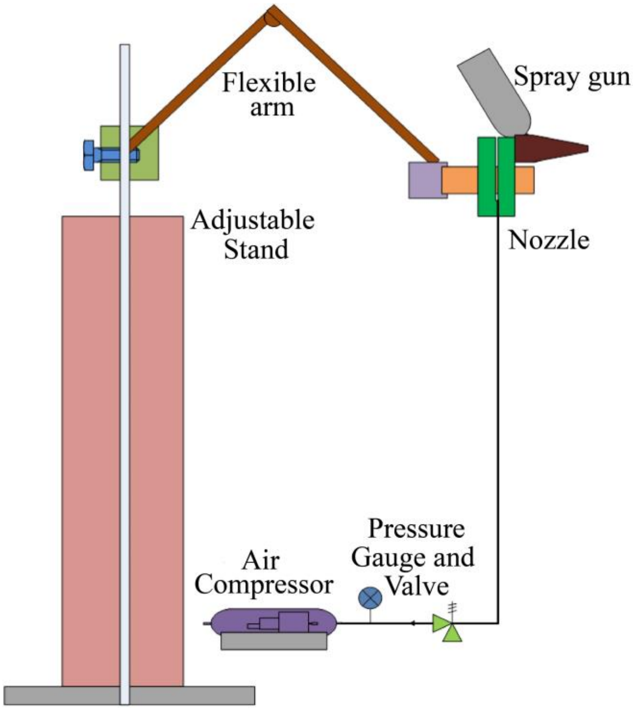

Fig. 2 Development of MQL setup

Fig. 3 Fanuc series Oi mate –TC CNC machine

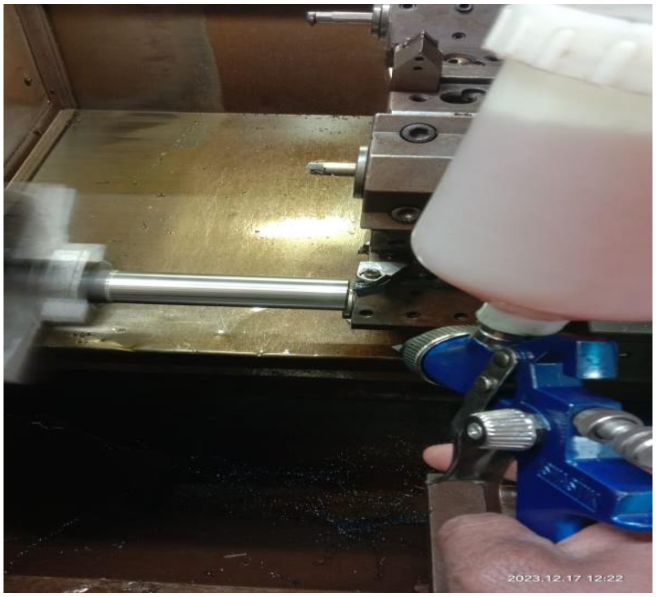
Fig. 4 Pictorial view of experimental setup

Table 1. Experimental condition

Work Material	AISI 1014 Steel **(**C: 0.36- 0.45 %, Mn : 0.6 -1 %, Si: 0.2 - 0.3%, S: 0.025 %, P: 0.015%)
Size of Specimen (Size mm)	(Ø38 mm X 200 mm)
Cutting Tool	Uncoated cemented carbide insert
Hardness	30 ± 2HRC, Heat Treated
Environment	(MQL) Mist application Lubricant (SiC & TiO_2) Nano particle (SiC - 50nm & TiO_2 - 20 nm)
Lubricating Oil (Base Fluid)	Palm Oil
Flow Rate (MQL)	40, 50, 60 ml/min
Pressure	3,4,5 bar respectively
Fanuc Series Oi Mate –TC CNC	135 mm bar X 25mm Power
Temperature Measurement	Digital Temperature gun
Process Parameter	Cutting Speed (m/min) – 700, 1000, 1300. Feed Rate (mm/rev) **-** 0.10, 0.15, 0.20 Depth of Cut (mm) – 0.8,0.9,1
Nanoparticle Concentration Vol. %	Palm oil SiC + Palm oil (1,2,3) Vol. % TiO_2 + Palm oil (1,2,3) Vol. % SiC + TiO_2 + Palm oil (1,2,3)Vol. %

The experiments were initiated the process parameter was considered as per Table 1. The temperature of work peace is measured by a digital temperature gun. To find out the surface roughness using the Surftest SJ-210 (Mitutoya Make).

4. Principal Component Analysis

This technique was first applied in the social sciences to identify and measure instances was carried out difficult to evaluate the exceptional changes directly. Principal component analysis is used for multi-objective data set analysis as well as data reduction. Nowadays, PCA is widely employed in a wide range of scientific fields. This primarily focuses on inter-object correlation analysis utilizing linear combinations for every performance metric. The principle components analysis approach can be used to find the best combinations for MQL Turning.

The following steps are adopted for the optimization.

Stage 1: Assign a signal-to-noise ratio to the experimental data

$$njj = -10\,log\left(\frac{1}{n}\sum_{j=1}^{n} yij2 =\right) \quad (1)$$

Stage 2: Nominal to Signal-to-Noise Ratio

$$X_i(j) = \frac{x_{xi}^{(0)} - \min_{xi}^{(0)}(j)}{\max_{xi}^{(0)}(j) - \min_{xi}^{(0)}(j)} \quad (2)$$

Stage 3: Determine the Matrix (Multiresponses)

$$x = \begin{bmatrix} x1(1)\ldots\ldots & x1(n) \\ xm(n)\ldots\ldots & xm(n) \end{bmatrix} \quad (3)$$

Stage 4: Evaluate the correlation coefficient array:

$$R_{ji} = \frac{\mathrm{cov(xi(j),xi(l)}}{\sigma_{xi}(j)\times\sigma_{xi}(l)}, j = 1,2..,nl = 1,2....n \quad (4)$$

Where $cov(xi(j), xi(l)$ the covariance of $xi(j)$ and $\sigma_{xi}(j) \times \sigma_{xi}(l)$, the standard deviation of sequence $\sigma_{xi}(l)$ the standard deviation of sequence $xi(l)$

Stage 5: determine eigenvalues and eigenvectors:

$$(R - \lambda_k I_m)V_{ik} = 0 \quad (5)$$

Stage 6: find our principal component

$$P_{ik} = \sum_{k=1}^{m} xi(j) \times Vjk \quad (6)$$

Step 7: Calculate the TPCI

$$P_i = \sum_{k=1}^{m} Pik \times ek \quad (7)$$

Where

$$ek = \frac{eig(k)}{\sum_{k=1}^{m} eig(k)} \quad (8)$$

$eig(k) = k^{th}$ eigenvalue

Step 8: Select the optimum levels of cutting parameters

$$V_1 = \frac{(TPCI)1+(TPCI)2+(TPCI)3+......+(TPCI)27}{27} \quad (9)$$

Stage 9: Determine the Combined Objective Function (COF)

$$\text{Weighted normalized} = wi \times \frac{\text{Measured Value of quality characteristics in each run}}{\text{Minimum value of quality characteristics in the data set}}$$

Wi = weightage assigned to the quality characteristics
$i = 1,2,\ldots\ldots,n$ and n is the number of quality characteristic

$COF = \sum$ *weighted* normal value for all set in each run

Stage 10: Applying the (ANOVA).

Stage 11: Carried out confirmatory test.

5. Design of Experiments

The process parameter and their levels are displayed in the experiments that are conducted using the design of experiments. Trials utilizing minimum quantity lubrication were set up using Table 2, L27 orthogonal array, and process parameters such as cutting speed, feed rate, and depth of cut. Minimum Quantity Lubrication (Biodegradable hybrid nanofluids) was carried out using the L27 orthogonal array. Different combinations of nanofluids were used, each with a different volume concentration, such as palm oil (without any emulsifier as the base fluid), silica and palm oil, titania and palm oil, and silica + tipo2 + palm oil, with volume concentrations of 1%, 2%, and 3%, respectively.

Trial experiments were conducted to determine the limits of the process variables by adjusting one while maintaining the other constant. This was done to determine the working range for temperature, material removal rate, and surface roughness range.

Table 2. Experimental trials of Taguchi approach

Factors	Levels		
	1	2	3
Cutting Speed (m/min)	700	1000	1300
Feed Rate (mm/rev)	0.10	0.15	0.20
Depth of Cut (mm)	0.8	0.9	1
Volume Concentration %	1	2	3
Flow Rate (ml/min)	40	50	60
Pressure-Bar	3	4	5

Table 2 shows that generalize the Taguchi approach to such experimental trials. In such experiments, the various combination of nano lubricants were (Palm oil as base fluid), SiC + palm oil, Palm oil +TiO_2, SiC+TiO_2 + Palm oil are the basic combination of biolubricants based hybrid nanofluids. All combination was carried out through experimentation using the Minimum Quantity Lubrication (MQL). In this paper, we have stated the experimentation of Palm oil, SiC + Palm oil, and its confirmation test was carried out.

6. Experimental Results and Discussion

The precise procedures for using principal components analysis to identify the optimal combinations of process parameters are covered in this section.

6.1. Optimum Combination of Process Parameter

Table 3 displays the experimental data in this manner. The set of trials, surface roughness, temperature, and material removal rate is chosen quality attributes that are consistent and favorable; the lower, is better.

The signal-to-noise ratios of temperature, surface roughness, and material removal rate are determined by substituting Equation (1). Basically, better quality attributes correspond with larger signal-to-noise ratios. Table 3 displays the normalized S/N ratios that were calculated using Equation (2).

From Equation (4), the correlation coefficient is derived. MATLAB is utilized to estimate the eigenvalues and eigenvectors of the correlation coefficient array. The symmetric matrices have eigenvalues, and their eigenvectors are primarily orthogonal to one another. Equation (5) is used to generate the computed eigenvalue (0.0272, 0.101, 0.1605) and the eigenvectors (0.615, -0.654, 0.433), (-0.788, -0.5394, 0.3074), and (-0.031, 0.5305, 0.8473) that correspond to these correlation coefficients. Table 4 shows that the normalized signal-to-noise ratio is stated below.

6.2. Obtaining the Principal Component

Using principal components analysis, correlated variables are converted into linear combinations of uncorrelated variables that together account for the majority of the variance in the initial set of data. Finding the principle components is the primary goal of PCA. There will be less than or equal to n principle components created if n is the number of linear combinations obtained. It is possible to determine the major component (PC1) for experiment 1 using Table 3 and Equation (6).

$$\text{PC1} = 0.998 \times 0.615 + 0 \times (-0.654) + 0.076 \times 0.433 = 0.091$$

Three primary components, PC1, PC2, and PC3 are identified since the current work addresses three replies. Table 4 contains the relevant values. Table 5 shows that the PCA and weighted normalized with contribution factor are stated below.

Table 3. Experiment on SiC and palm oil

Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut(mm)	Vol. %	Flow rate (ml/min)	Pressure (bar)	Temperature °C	Surface Roughness	MRR mm^3/min
700	0.1	0.8	1	40	3	104.0	0.567	4670.027232
700	0.1	0.8	1	50	4	103.0	0.879	4815.965583
700	0.1	0.8	1	60	5	104.0	1.443	4670.027232
700	0.15	0.9	2	40	3	103.0	1.536	11189.45188
700	0.15	0.9	2	50	4	102.0	1.536	9846.070649
700	0.15	0.9	2	60	5	103.0	1.316	8019.345405
700	0.2	1	3	40	3	103.0	1.389	10464.10568
700	0.2	1	3	50	4	102.0	0.725	4935.468451
700	0.2	1	3	60	5	104.0	1.235	10425.47849
1000	0.1	0.9	3	40	4	103.0	1.563	10425.47849
1000	0.1	0.9	3	50	5	102.0	1.789	9556.480336
1000	0.1	0.9	3	60	3	103.0	1.345	4157.762531
1000	0.15	1	1	40	4	103.0	1.543	10868.66869
1000	0.15	1	1	50	5	104.0	1.256	6807.680051
1000	0.15	1	1	60	3	103.0	1.347	6330.996388
1000	0.2	0.8	2	40	4	104.0	1.836	11545.66699
1000	0.2	0.8	2	50	5	102.0	0.623	7335.30332
1000	0.2	0.8	2	60	3	103.0	1.749	7419.487872
1300	0.1	1	2	40	5	104.0	1.487	10568.73992
1300	0.1	1	2	50	3	103.0	1.127	6728.011472
1300	0.1	1	2	60	4	104.0	1.236	7489.812079
1300	0.15	0.8	3	40	5	103.0	1.673	6688.177183
1300	0.15	0.8	3	50	3	104.0	1.567	19156.30975
1300	0.15	0.8	3	60	4	102.0	1.536	10386.8513
1300	0.2	0.9	1	40	5	103.0	1.324	8958.731676
1300	0.2	0.9	1	50	3	102.0	1.234	8056.836501
1300	0.2	0.9	1	60	4	103.0	1.247	10153.76036

Table 4. Normalize signal to noise ratios

Expt. No.	Signal to Noise Ratio			Normalized Signal to Noise Ratio		
	Temp	Ra	MRR	Temp	Ra	MRR
1	-40.341	4.928	73.386	0.998	0.000	0.076
2	-40.257	1.120	73.654	0.501	0.373	0.096
3	-40.341	-3.185	73.386	0.998	0.795	0.076
4	-40.257	-3.728	80.976	0.501	0.848	0.648
5	-40.172	-3.728	79.865	0.000	0.848	0.564
6	-40.257	-2.385	78.083	0.501	0.717	0.430
7	-40.257	-2.854	80.394	0.501	0.763	0.604
8	-40.172	2.793	73.867	0.000	0.209	0.112
9	-40.341	-1.833	80.362	0.998	0.663	0.602
10	-40.257	-3.879	80.362	0.501	0.863	0.602
11	-40.172	-5.052	79.606	0.000	0.978	0.545
12	-40.257	-2.574	72.377	0.501	0.735	0.000
13	-40.257	-3.767	80.724	0.501	0.852	0.629
14	-40.341	-1.980	76.660	0.998	0.677	0.323
15	-40.257	-2.587	76.029	0.501	0.736	0.275
16	-40.341	-5.277	81.248	0.998	1.000	0.669
17	-40.172	4.110	77.308	0.000	0.080	0.372
18	-40.257	-4.856	77.407	0.501	0.959	0.379
19	-40.341	-3.446	80.480	0.998	0.821	0.611

20	-40.257	-1.038	76.558	0.501	0.585	0.315
21	-40.341	-1.840	77.489	0.998	0.663	0.385
22	-40.257	-4.470	76.506	0.501	0.921	0.311
23	-40.341	-3.901	85.646	0.998	0.865	1.000
24	-40.172	-3.728	80.330	0.000	0.848	0.599
25	-40.257	-2.438	79.045	0.501	0.722	0.503
26	-40.172	-1.826	78.123	0.000	0.662	0.433
27	-40.257	-1.917	80.133	0.501	0.671	0.584

Table. 5 Principal component and coefficient of factor

Expt. No	Principal Component			TPCI	Weighted Normalized			COF
	PC1	PC2	PC3		Temp	Ra	MRR	
1	-0.091	0.488	0.869	0.7460925	0.336470588	0.370658251	0.333	1.04013
2	0.138	-0.030	0.616	0.3388754	0.333235294	0.382241321	0.516238095	1.23171
3	0.398	-0.032	1.213	0.6945207	0.336470588	0.370658251	0.84747619	1.55461
4	-0.005	-0.638	0.991	0.1959133	0.333235294	0.888102457	0.902095238	2.12343
5	0.077	-0.859	0.541	-0.1696880	0.33	0.78147881	0.902095238	2.01357
6	0.086	-0.435	0.867	0.2487613	0.333235294	0.636492335	0.772888889	1.74262
7	-0.023	-0.559	0.941	0.2103828	0.333235294	0.830532011	0.815761905	1.97953
8	0.040	-0.197	0.125	-0.0363667	0.33	0.391726217	0.425793651	1.14752
9	-0.098	-0.228	1.318	0.5962811	0.336470588	0.827466186	0.72531746	1.88925
10	0.041	-0.623	0.984	0.2043588	0.333235294	0.827466186	0.917952381	2.07865
11	0.172	-0.933	0.591	-0.1741348	0.33	0.758494139	1.05068254	2.13918
12	0.437	-0.215	0.743	0.3349411	0.333235294	0.33	0.789920635	1.45316
13	0.013	-0.631	0.987	0.1995316	0.333235294	0.86264202	0.906206349	2.10208
14	0.131	-0.087	1.238	0.6520468	0.336470588	0.540322926	0.737650794	1.61444
15	0.220	-0.364	0.828	0.2789235	0.333235294	0.502488729	0.791095238	1.62682
16	0.057	-0.485	1.484	0.5608132	0.336470588	0.916375113	1.078285714	2.33113
17	-0.244	-0.253	0.149	-0.0807081	0.33	0.58220018	0.365888889	1.27809
18	0.275	-0.565	0.957	0.2433997	0.333235294	0.588881876	1.027190476	1.94931
19	-0.008	-0.337	1.389	0.5842138	0.336470588	0.83883679	0.87331746	2.04862
20	0.096	-0.286	0.775	0.2806774	0.333235294	0.533999662	0.661888889	1.52912
21	0.073	-0.112	1.251	0.6402299	0.336470588	0.594463481	0.725904762	1.65684
22	0.306	-0.504	0.919	0.2596565	0.333235294	0.53083803	0.982555556	1.84663
23	-0.287	-0.576	1.528	0.5022049	0.336470588	1.520428878	0.920301587	2.7772
24	0.049	-0.878	0.552	-0.1768008	0.33	0.824400361	0.902095238	2.0565
25	0.032	-0.477	0.892	0.2336909	0.333235294	0.71105106	0.777587302	1.82187
26	0.066	-0.666	0.420	-0.1309227	0.33	0.639467989	0.724730159	1.6942
27	-0.064	-0.488	0.895	0.2203417	0.333235294	0.805900023	0.732365079	1.8715

6.3. Calculate Total Principal Component

In order to determine the most optimal levels, the total principal component is computed by applying Equations (7) and (8). TPCI for experiment number one is therefore determined as follows,

$$(TPCI)1 = (PC)1 \times (-0.0091) + (PC)2 \times 0.033 + (PC)3 \times 0.0535 = 0.7460925$$

Table 5 displays all of the computed TPCI values in the appropriate manner.

6.4. Create a Response Table to Choose the Best Parameters

Building the response table comes next, following the computation of the TPCIs for each trial run. For example, applying Equation (9) to determine the factor level yields the following result.

$$\overline{V} = \frac{(TPCCI)1 + (TPCI)2 + \ldots\ldots (TPCI)9}{9}$$

$$\overline{V} = \frac{0.746 + 0.3380 + 0.069 + 0.0195 + (-0.169) + 0.284 + 0.210 + (-0.036) + 0.596}{9} = 2.824$$

Other response values that correspond to the factors and their related levels are calculated using this procedure. The anticipated optimum factor level is given by the maximum TPCI value for each factor.

Using Equation (10), the (COF) for quality characteristics was determined by giving each quality characteristic an equal weight of 0.33. The COF values for each experimental run are displayed in Table 5.

6.5. Analysis of Variance (ANOVA)

For COF, an ANOVA is performed to ascertain the factors that have a significant impact on performance metrics. All the levels (at α = 0.05 at 90% optimum level) for such variation linked to the F-value are shown in Table 6. According to the F-test principle, there will be a higher effect on the performance characteristics of F is bigger for a given factor. In our case, the feed rate in the ANOVA table has the largest F value, contributing a total of 33.6%, which amply justifies the major influence on performance measures like surface roughness, material removal rate, and temperature. With a contribution of 14%, pressure as the second significant component. It was discovered that the Vol % contributed 13.07 percent, whereas the cutting speed contributed 12.3%. The flow rate contributed 10.76%, the depth of cut contributed at 8.9%, and the error-related contribution was minimal, indicating that significant factors were not overlooked and that there was no major measurement error.

6.6. Confirmation Test

Table 7 shows the findings of validation tests utilizing the optimal parameters (surface roughness, temperature, MRR) discovered by PCA using the initial setup level. Applications of PCA for simultaneous optimization of all three responses have been found to improve the outcomes significantly.

Table 6. ANOVA result for the (COF)

Source	DOF	Sum of Squares	Mean Square	F – Value	P-Value	Contribution %	Remark
Model	6	74.45	10.44	24.46	<0.001		Significant
Cutting Speed	1	3.2	2.4	2.14	0.019	12.3	
Feed Rate	1	70.3	33.6	33.55	<0.002	31.57	Significant
DOC	1	2.33	1.18	2.45	0.747	8.9	
Vol. %	1	3.4	2.5	3.14	0.003	13.07	
Flow Rate	1	2.8	1.1	2.11	0.028	10.76	
Pressure	1	3.8	3.8	3.12	0.871	14.6	
Error	20	2.3	22			8.8	
Total	26						

$R^2 = 0.8912$; $R^2_{Adj} = 0.8560$

Table 7. Initial and optimal setting of results

	Initial Setting as per Machining Data Handbook	Optimal Setting using PCA
Setting Level	cs= 700,fr = 0.1; doc =0.8	cs= 700, fr = 0.1; doc =0.8 ; 1 vol%; pressure = 40; flow rate = 3
Surface Roughness	0.567	0.357
Temperature	104.0	104.0
MRR	4670.027232	11189.45188
COF	2.33113	1.106842276
% Improvement in COF = 70		

Table 7 illustrates the issue at hand, which is that the temperature remains constant during the cutting process. The material removal rate is increased while the surface roughness is reduced from 0.567 µm to 0.357 µm. Confirmation testing shows that the proposed procedure yields significantly better results than the current methodology.

7. Conclusion

Utilizing minimum quantity lubrication, the cutting process parameter during the turning of AISI 1040 medium carbon steel was optimized through the application of principal component analysis. The findings allow for the formulation of the following conclusion.

1. The out parameters, such as surface roughness, temperature, and Material Removal Rate (MRR) of the cutting parameter using principal component analysis, as shown in Table 7. The set of cutting speed (700 m/min), feed rate (mm/rev), depth of cut (mm), vol %, Flow rate (ml/min) and pressure (bar).
2. The results of the confirmation test indicate a 63% increase in surface roughness and a 41% drop in the rate of material removal. When all three objectives are taken into account, the overall improvement is 70% more than the current parameter.
3. The present study shows that the surface roughness of 0.357 µm obtained during the turning of AISI 1040 steel material, based on the principal component analysis, is suitable for the turning parameter.
4. The various parameter and their levels show the highest effect on surface roughness with 38% weightage, 46% weightage for material removal rate and 16% weightage of temperature.
5. The optimization outcomes achieved by the suggested method offer operators and tool manufacturers an easy-to-use reference.

Now it shows that The PCA approach is very appropriate for tackling difficulties related to temperature quality, surface roughness, and material removal rate in turning. For tool condition monitoring systems, the cutting speed may be predicted in the future using the cutting forces recorded during the trial run.

The cutting speed created during the machining process are significant characteristics that indicate the machining condition.

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