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ALOE VERA AS CUTTING FLUID OPTIMIZATION USING RESPONSE SURFACE METHOD

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За допомогою аналізу поверхні відгуку (RSM) вирішується задача оптимізації шорсткості поверхні (Ra) та зносу бічної поверхні (VB) в процесі обробки з використанням рідини на основі алое вера (AVCF). Для цього на основі реалізації двадцяти циклів експериментального випробування отримано рівняння множинної квадратичної регресії, в якій за вхідні змінні обрано швидкість подачі (f), глибина різання (a) та тип AVCF (1, 2 і 3). Отримано оптимальний процес з наступними параметрами: f=0,140 мм/об, a=2,0556 мм, AVCF=71,8970 cSt, що забезпечують мінімум Ra та f=0,20 мм/об, a=2,50 мм, а AVCF= =8,8050 cSt – забезпечують мінімум VB

Ключові слова: Optimization, Aloe Vera, Flank Wear, Surface Roughness

С помощью анализа поверхности отклика (RSM) решается задача оптимизации шероховатости поверхности (Ra) и износа боковой поверхности (VB) в процессе обработки с использованием жидкости на основе алоэ вера (AVCF). Для этого на основе реализации двадцати циклов экспериментального испытания получено уравнение множественной квадратичной регрессии, в которой за входящие переменные выбрана скорость подачи (f), глубина резания (a) и тип AVCF (1, 2 и 3). Получено оптимальный процесс со следующими параметрами: f=0,140 мм/об, a=2,0556 мм, AVCF=71,8970 cSt, которые обеспечивают минимум Ra и f=0,20 мм/об, A=2,50 мм, а AVCF=8,8050 cSt – обеспечивают минимум VB

Ключевые слова: Optimization, Aloe Vera, Flank Wear, Surface Roughness

1. Introduction

Cutting fluids are used in the turning process to decrease the tool wear rate and surface roughness of the turning product. The most common types of cutting fluids are oil-based and water-miscible fluids. Recently, due to environmental issues, cutting fluid alternatives have been developed, such as vegetable oil-based options. The development of the turning process is accelerating and increasingly complex in line with increasing demand and increasing product quality and decreasing production costs. Factors affecting the cutting process include the type of workpiece material, the type of cutting tool, the cutting conditions (cutting speed, depth of cut and feeding), cutting fluid, type of machining process used. Based on the above, especially the eco-friendly technology challenge, a study of the utilization and potential of aloe vera as a cutting fluid will be developed.

Therefore, the aim of the present study was to optimize variables of the turning process with Aloe Vera as cutting fluid such as feeding, depth of cut and Aloe Vera cutting fluid type using response surface methodology.

2. Literature review and problem statement

The study of vegetable oil-based cutting fluids as an environmentally friendly mode of machining was performed with similar performance obtained using mineral oil-based metalworking fluids in [1]. Bio-oils using in machining with palm oil for turning, mixtures of solid lubricants such as boric acid in palm oil in Ti-6Al-4V alloys were studied at the cutting process. Experimental results on the performance of three cutting conditions such as dry, palm oil, blend of palm oil and boric acid lubricating in terms of surface roughness were presented. The result of optimal cutting parameters with Taguchi methods was studied in [2]. In the next study, vitamin C from a rich lemon fruit extract was used as an antioxidant to improve the oxidative stability of the vegetable oils. Based on this study, groundnut oil and palm oil were recommended as alternative lubricants to the mineral oil during machining of mild steel [3]. The observations of uniform flank wear, micro-chipping, thermal cracking, and flaking on the MQL palm oil (MQLPO) were provided in the high-speed drilling of Ti-6Al-4V [4]. In order to reduce pollutant emissions in the field of cutting techniques, research on Minimum Quantity Lubrication (MQL) and Cooling (MQC) has been found and developed. This study aims to investigate the machinability of Ti-48Al-2CR-2NB (at. %) alloys. The results of the evaluation of wear and tear of cutting tools and cutting tool life, surface quality, lubricant consumption, and environmental impact are examined with reference to MQL, wet and dry cutting [5]. 100 ml/hr or less is often used for MQL cooling. A discussion of the optimization of process parameters on surface roughness occurring on Ti-6Al-4V with different cooling conditions such as dry, flooded and Minimum Quantity Lubrication, different cutting tools such as CVD coating equipment, PVD coated equipment and uncoated tools using the methodology Taguchi design was provided. The result for the MQL conditions is minimum surface roughness compared to dry and flood conditions. The optimum conditions occur at medium cutting speed, low feed rate and high cutting depth. Observation of wear with optical images shows lower wear compared to dry and stagnant machines [6]. Trends in environmental issues and the development of regulations on contamination and pollution, the challenge of producing renewable and biodegradable cooling fluids are important issues today. Understanding of the type of cutting fluid and machining process parameters is a skill and analysis that must be mastered to maximize the efficiency of cutting fluid in the machining process. Generally, the heat generated occurs in the cutting zone due to friction on the chip-interface interface, and friction between the clearance of the tool surface and the workpiece that determines the surface quality of the workpiece. The growing research on bio-based cooling fluids has significantly reduced the ecological problems caused by mineral-based cutting fluids in [7]. The effect of various levels of cutting fluid and cutting parameters on surface roughness and wear of the chisel has been studied. Optimization by utilizing the Taguchi method is used to minimize the number of experiments. Some research results indicate that feeding becomes the dominant factor contributing 34.3 % to surface roughness. The flow rate of the cutting fluid also shows a significant contribution (33.1 %). However, cutting speed and cutting depth show a little contribution to surface roughness. On the other hand, cutting speed (43.1 %) and cutting depth (35.8 %) were the dominant factors affecting the life of the cutting tool. However, the application of cutting with coolant (13.7 %) shows considerable contribution. Optimum cutting conditions to reduce surface roughness at high cutting speed, intermediate level of cutting depth, low level of feeding and coolant fluid velocity have also been studied intensively [8]. Titanium alloys are very difficult to cut because they have high strength and high resistance to heat. Excessive heat is due to poor thermal conductivity near the cutting edge, thus accelerating the wear of cutting tool. It is required to reduce heat effectively for cooling; in order to implement high cutting speed. The measurement of the high effect and the effect of carbon dioxide snow (CO_2-snow) as innovative cooling methodologies in machining of three tempers of b-titanium alloy is described in the paper. As cooling techniques, the following were used: conventional flood emulsion; impingement of jet of CO_2-snow at the rake face, the flank face, the rake and flank faces together; and the combination of the CO_2-jet and MQL. The evaluation takes place on cutting forces, tool wear, and acoustic emission as an indicator to measure differences in terms of the chip morphology [9]. The research results showed that the MQL condition, which has cooling and lubricating effects, was found to have a more significant influence in improving the tool life as compared to dry condition. Furthermore, the (nc-AlTiN)/(a-Si_3N_4) coated tool was confirmed to be more suitable for machining of titanium alloy than (nc-AlCrN)/(a-Si_3N_4) coated tool under MQL condition, which emphasizes the significance of matching between cutting fluids and coating materials. The slower wear rate of (nc-AlTiN)/(a-Si_3N_4) coated tool in the MQL condition was obtained than that of the (nc-AlCrN)/ (a-Si_3N_4) coated tool. As a result, the MQL condition can greatly prolong the tool life of (nc-AlTiN)/(a-Si_3N_4) coated tool while has minor influence on improving the tool life of (nc-AlCrN)/(a-Si_3N_4) coated tool. Adhesive wear was observed to be the main wear type. The MQL technique not only has cooling and lubricating effects on Nano-composite coated tool, but also helps to form a powerful protective layer. In addition, in the MQL condition, the (nc-AlTiN)/(a-Si_3N_4) coated tool only suffered adhesive wear while the (nc-AlCrN)/(a-Si_3N_4) coated tool suffered adhesive, diffusion and oxidation wear [10]. The power from a cutting process of the metal is converted to heat at the edges of the cutting tool. To improve the tribological characteristics of the machining process and to dissipate the heat generated, the use of cutting fluids is required. Conventional cutting fluids are still being questioned about adverse impacts on the environment and human health. Therefore, trends are geared towards alternatives such as vegetable oils (VOs). VOs offer a combination of both high biodegradability and lubrication, environmental friendliness and compatibility with additives, low toxicity and volatility, high flash point and high viscosity index. Impacts of VOs-based cutting fluids, cutting tool materials and working conditions were investigated. Two sets of experimental plans designed consisting of 25 and 27 tests with variance analysis (ANOVA) were used to evaluate the effect of process variables on Ra and wear. In general, Ra surface roughness ranges from 0.56 μm and 1.81 μm and statistical analysis shows that the main factor for Ra is the Process Capability ratio (PCR) or Process Capability Ratio of 94.4 % feeding. A noticeable increase in wear of the edges of the chisel is recorded when high cutting speeds are used [11]. Cutting fluids provide a potential to reduce the environmental effects. This study discusses aloe vera cutting fluids (AVCFs) as an environmentally-friendly alternative solution to using oil-based cutting fluids (OBCFs). Observations by measuring the flank wear of the cutting tool were carried out. The flank wear result of AVCF was 0.311 mm and that of OBCF was 0.284 mm, while that of dry machining was 0.576 mm. Flank wear of the cutting tool using AVCF is almost equivalent to that of the cutting tools using OBCFs. Thus, AVCF has a great potential as an environmentally friendly cutting fluid compared to OBCFs [12]. From several studies on the cutting fluids that have been done, an environmentally friendly alternative cutting fluid is required. The determination of the turning process parameters and the use of alternative liquids from the plant will help optimize the process and in maintaining the wear level of the cutting tool to produce a product with a good surface. The response surface methodology (RSM) method is required in solving modeling and analysis problems responsively to obtain optimal results.

3. The aim and objectives of the study

In the earlier study, aloe vera was investigated as a cutting fluid during the turning process as a challenge study to reduce the environmental effects. Aloe vera has potential as a standard cutting fluid.

We solved the following tasks to achieve the objective:

– to find the effect of cutting parameters on surface roughness and flank wear;

– to receive the RSM model of surface roughness (*Ra*) and flank wear (*VB*);

– to perform a parametric study and predict the optimum parameters of cutting using Aloe Vera as alternative cutting fluid.

4. Materials and methods of research

The research method used in this study was a true experimental research method used to determine the effect of turning process parameters: cutting speed, depth of cut, and type of cutting fluid, which affects the flank wear and surface roughness. The turning process used was wet cutting. The test material used was ST42 steel with the following mechanical properties: yield strength 396.9 MPa and tensile strength 661.0 MPa and chemical properties of ST42 (Table 1, 2). The specimen geometry is a solid cylinder with a diameter of 38 mm and a length of 500 mm (Fig. 1).

Table 1

Mechanical Properties of workpiece

Material	St.42
Mechanical properties of the workpiece:	
Yield Strength (σ_v, MPa)	396.9
Tensile Strength (σ_u, MPa)	661.0
Elongation (ε, %)	20.50
Reduction of Area (δ, %)	39.58

Table 2

Chemical Properties of workpiece

Name	C	Si	Mn	P	S	Fe
St.42	0.21 %	0.46 %	1.35 %	0.05 %	0.06 %	97.87 %

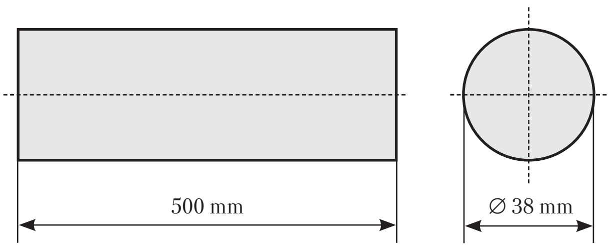

Fig. 1. Geometry of workpiece

A high-speed steel (HSS) cutting tool with a hardness of 67.25 HRC is used (Table 3). The specification of the tool geometry is the following: side relief angle 8°, side rake angle 10°, side cutting edge angle 14°, end cutting edge angle 7°, end relief angle 7°, and back rack angle 10° (Fig. 2).

Table 3

Properties of cutting tool

Name	Load	Indenter	Rockwell Hardness (HRC)	On the average HRC
HSS	150	Diamond	67; 65; 67; 66; 67; 70; 67; 65	67.25

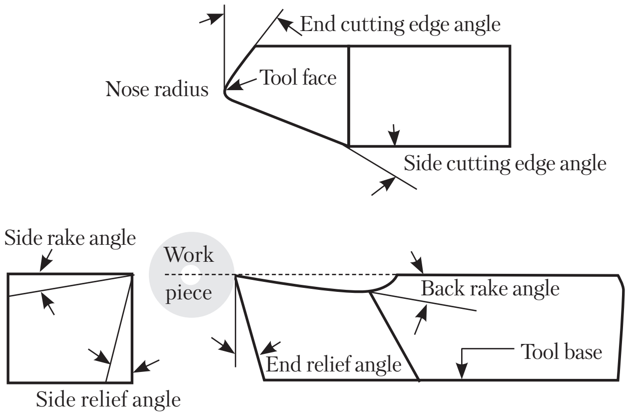

Fig. 2. Turning tool geometry

The design of the experimental method was used to perform the experimental work in a planned manner and to investigate the interaction effect between the various parameters considered. The relationship between output responses (output parameters) and input parameters was determined using the RSM. In this study, surface roughness (*Ra*) and flank wear (*VB*) variables were set through a second-order polynomial expression. The factors of feed rate (f), cut depth (a), and aloe vera cutting fluid (AVCF) and the response variables *Ra* and *VB* can be related using the expression: $Ra = Ra(f, a, \text{AVCF})$ and $VB = VB(f, a, \text{AVCF})$. Table 4 shows factors and levels of the experimental design in this study. The process parameters of turning were selected based on the condition of the turning machine. Cutting fluids derived from aloe vera were processed based on viscosity levels (Table 5).

Table 4

Factors and levels of the experimental design

No.	Factor	Level –1	Level 0	Level 1
1	f [mm/rev]	0.14	0.16	0.2
2	a [mm]	1.5	2	2.5
3	Aloe Vera CF Types (AVCF Types)	Type 1	Type 2	Type 3

Table 5

Plot experiment with the RSM method

No.	Parameter			Response	
	F [mm/put]	*A* [mm]	AVCF Types (cSt)	*Ra* [μm]	*VB* [mm]
1	–1.000	–1.000	–1.000	–	–
2	–1.000	–1.000	1.000	–	–
3	0.000	0.000	0.000	–	–
4	0.000	0.000	1.000	–	–
5	0.000	–1.000	0.000	–	–
6	1.000	–1.000	1.000	–	–
7	0.000	0.000	0.000	–	–
8	0.000	0.000	0.000	–	–
9	1.000	0.000	0.000	–	–
10	–1.000	1.000	1.000	–	–
11	1.000	1.000	1.000	–	–
12	0.000	0.000	–1.000	–	–
13	–1.000	1.000	–1.000	–	–
14	0.000	0.000	0.000	–	–
15	1.000	–1.000	–1.000	–	–
16	0.000	0.000	0.000	–	–
17	1.000	1.000	–1.000	–	–
18	–1.000	–1.000	–1.000	–	–
19	–1.000	–1.000	1.000	–	–
20	0.000	0.000	0.000	–	–

The experiment involved three types of aloe vera (AVCF) intake: Aloe vera gel filtered as a cut-off with 80 mesh. AVCF type 1 is a non-filtered aloe vera liquid with a viscosity value of 71.897 cSt; AVCF type 2 is a filtered aloe vera liquid having a viscosity value of 17.293 cSt; AVCF type 3 is a filtered aloe vera with aloe vera skin with a viscosity value of 8.805 cSt (Fig. 3).

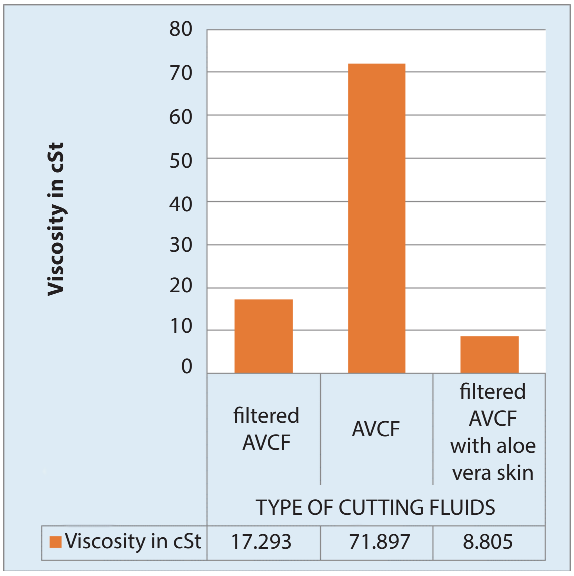

Fig. 3. Viscosity value by type of cutting fluid

The experimental design was performed following Table 5, for AVCF type by introducing the numerical price of its viscosity value. Measurement of flank wear using microscope tool and Surface Roughness measurement with surface tester were performed, all data were processed by the RSM method (Fig. 4).

5. Experimental data and processing of the obtained results of experiment

Based on the research results, it can be stated that:

$$\begin{aligned}Ra &= 5.2495+0.1536f+0.1775a-0.2332\text{AVCF}-\\&-0.7356f^2+1.8455a^2-1.1298\text{AVCF}^2+\\&+0.1555fa+0.1122f\text{AVCF}-0.4477a\text{AVCF}.\end{aligned} \quad (1)$$

From the regression equation for surface roughness (Ra), it can be observed that the effect of the square variable from the depth of cut (a) is very significant to the effect of surface roughness of the workpiece. As for the regression equation:

$$\begin{aligned}VB &= 0{,}2681-0{,}0086f+0{,}0126a+0{,}0081\text{AVCF}-\\&-0{,}0134f^2+0{,}0004a^2-0{,}0296\text{AVCF}^2-\\&-0{,}0254fa+0{,}0105f\text{AVCF}+0{,}0069a\text{AVCF}.\end{aligned} \quad (2)$$

The use of Aloe Vera Cutting Fluids (AVCF) has a very significant effect on the occurrence of flank wear. The advantages of this study are aloe vera cutting fluids with the chemical composition, which does not directly harm the environment and human health: there are components of Energy (1.73–2.30 Calories), Protein (0.10–0.06 gram), Fat (0.05–0.09 grams), Carbohydrate (0.30 gram), Calcium (9.92–19.920 milligrams), Iron (0.060–0.320 milligrams), Vitamin A (2.00–4.460 IU), Vitamin C (0.50–4.20 milligrams), Thiamin (0.003 to 0.040 milligrams), Riboflavin (0.001–0.002 milligrams), Niacin (0.038–0.040 milligrams), Fibers (0.30 grams), Ash (0.10 gram), Water content (99.20 gram) [13].

While the lack of the results of this study is not yet investigated emulsion process of aloe vera fluid that occurs for turning process that supports its function as cutting fluid.

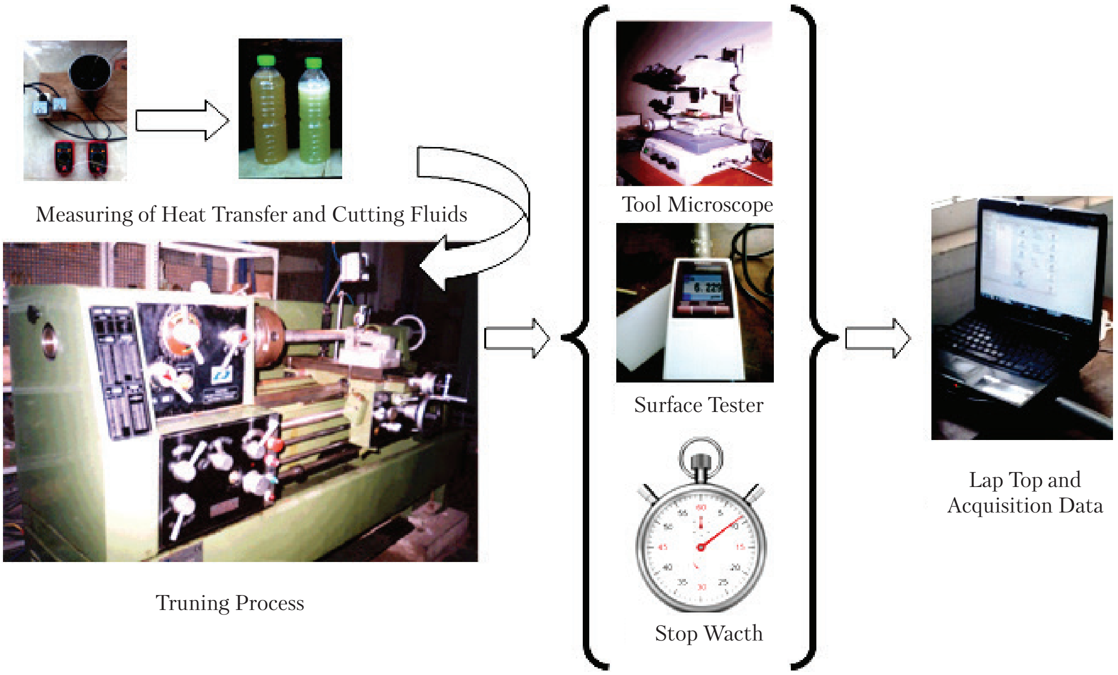

Fig. 4. Experimental design

This research needs to be developed, to obtain an aloe vera fluid that matches the required criteria, where the aloe vera fluid can be used as a standard cutting fluid for machining processes.

Table 6 describes the factors and corresponding responses in the cutting process design. From Table 7, $a*a$ has the most significant effect on the surface roughness of the turning samples. Based on the ANOVA results of Table 8, the statistical significance of each parameter can be found by comparing the mean square against an estimate of the experimental error. In this case, two effects, $a*a$ and a*CF, had p-values <0.05 or a statistical significance at a confidence level of 95 %.

Table 6

Factors and corresponding responses for cutting process design

No.	Parameter			Response	
	f (mm/rev)	a (mm)	AVCF Types (cSt)	Ra (μm)	VB (mm)
1	0.14	1.5	71.897	5.3621	0.181
2	0.14	1.5	8.805	5.1069	0.172
3	0.16	2	17.293	5.1569	0.202
4	0.16	2	8.805	3.8610	0.233
5	0.16	1.5	17.293	6.0046	0.223
6	0.2	1.5	8.805	4.4535	0.235
7	0.16	2	17.293	4.9823	0.22
8	0.16	2	17.293	4.4201	0.254
9	0.2	2	17.293	4.0536	0.205
10	0.14	2.5	8.805	5.5874	0.273
11	0.2	2.5	8.805	6.7441	0.169
12	0.16	2	71.897	4.0138	0.235
13	0.14	2.5	71.897	4.5759	0.267
14	0.16	2	17.293	4.0746	0.265
15	0.2	1.5	71.897	5.7130	0.232
16	0.16	2	17.293	5.4564	0.246
17	0.2	2.5	71.897	4.7215	0.243
18	0.14	1.5	71.897	4.4723	0.207
19	0.14	1.5	8.805	5.3075	0.228
20	0.16	2	17.293	4.3716	0.338

Table 7

Coefficients of the regression response surface models, estimated regression coefficients for Ra

Term	Coef.	*SE* Coef.	*T*	*P*
Constant	5.2495	0.5859	8.96	0
f	0.1536	0.1793	0.857	0.412
a	0.1775	0.1817	0.977	0.352
AVCF	–0.2332	0.1673	–1.393	0.194
f^2	–0.7356	0.5377	–1.368	0.201
a^2	1.8455	0.4717	3.912	0.003
AVCF^2	–1.1298	0.8601	–1.314	0.218
fa	0.1555	0.1841	0.844	0.418
fAVCF	0.1122	0.1787	0.628	0.544
aAVCF	–0.4477	0.1795	–2.494	0.032

Table 8

Analysis of variance (ANOVA) for *Ra*

Source*	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Regression	9	7.7378	7.7378	0.8598	2.77	0.064
Linear	3	0.2344	1.1911	0.397	1.28	0.334
f	1	0.0642	0.2278	0.2278	0.73	0.412
a	1	0.0024	0.2961	0.2961	0.95	0.352
AVCF	1	0.1679	0.6023	0.6023	1.94	0.194
Square	3	5.3332	5.7536	1.9179	6.18	0.012
f^2	1	1.0355	0.5806	0.5806	1.87	0.201
a^2	1	3.8239	4.7491	4.7491	15.31	0.003
AVCF^2	1	0.4739	0.5354	0.5354	1.73	0.218
Interaction	3	2.1701	2.1701	0.7234	2.33	0.136
fa	1	0.214	0.2212	0.2212	0.71	0.418
fAVCF	1	0.0258	0.1223	0.1223	0.39	0.544
aAVCF	1	1.9304	1.9304	1.9304	6.22	0.032
Residual Error	10	3.1029	3.1029	0.3103	–	–
Lack-of-Fit	3	1.2605	1.2605	0.4202	1.6	0.274
Pure Error	7	1.8425	1.8425	0.2632	–	–
Total	19	10.8407	–	–	–	–

*Note: * – Coef (Coefficient); SE Coef (Sum of Error Coefficient); T (Value T); DF (Degree of freedom); Seq SS (sequence sum of squares); Adj SS (adjust sum of squares); Adj MS (adjust Middle of squares); F (value F); P (Probability)*

Therefore, the verified model of the surface roughness is shown by the following equation:

$$\begin{aligned} Ra = {} & 5.2495 + 0.1536f + 0.1775a - 0.2332\text{AVCF} - \\ & - 0.7356f^2 + 1.8455a^2 - 1.1298\text{AVCF}^2 + \\ & + 0.1555fa + 0.1122f\text{AVCF} - 0.4477a\text{AVCF}. \end{aligned} \tag{3}$$

Fig. 7 shows the values of the turning process parameters with Aloe vera as the most optimum cutting fluid on the surface roughness response is feed rate (0.140 mm/rev), Cut Depth (2.0556 mm), and Aloe vera with Viscosity (71,8970 cSt).

The effects of the turning process parameters on the surface roughness and flank wear are examined. As the model is built and verified, it can be used to generate plots to show the effect of process factors on the surface roughness and flank wear. These plots are generated and discussed here. However, reading the 3D surface and contour graphs requires some sort of careful attention to not draw any misleading or conflicting conclusions. To simplify interpretation of the results, the effect of each factor will be considered, as it exists separately. Then, the overall interpretation of the whole plot will be done.

The 3D surface plot and the contour plot of the effects of the feed rate (mm/rev), cut depth (mm) and AVCFs (cSt) (response) of the surface roughness are given. As shown by the 3D surface plot, by increasing the feed rate, the surface roughness increased. This roughness increase continues until the feed rate reaches about 0.175 mm/rev, where increasing the feed rate further decreases the roughness.

Therefore, according to this plot, an optimum (maximum) surface roughness setting was achieved with the feed rate value of around 0.175 mm/rev (Fig. 5).

Regarding the effect of the cut depth, as shown in (Fig. 5), increasing the cut depth beyond the lower level of 1.5 mm, the roughness has shown a decreasing trend. This decrease continued until reaching a minimum surface roughness at a cut depth of approximately 2.0 mm, and then it started increasing again until it reached approximately the same starting measurement with a cut depth of 2.5 mm. This is evident from the approximately U-shaped surface of the speed side of the 3D surface plot.

This is supported by the contour plot of (Fig. 6), where it is also evident from the colored contour of blue of the 2.0 mm value, which can be achieved by varying both the cut depth and feed rate. This agrees well with the 3D surface plot finding mentioned above.

Therefore, based on the given feed rate and cut depth ranges, we can conclude that, if a high roughness is required, then it is recommended that the feed rate is maintained at around 0.17 mm/rev. However, this finding needs to be compared with other plot findings, as it might be further refined or confirmed.

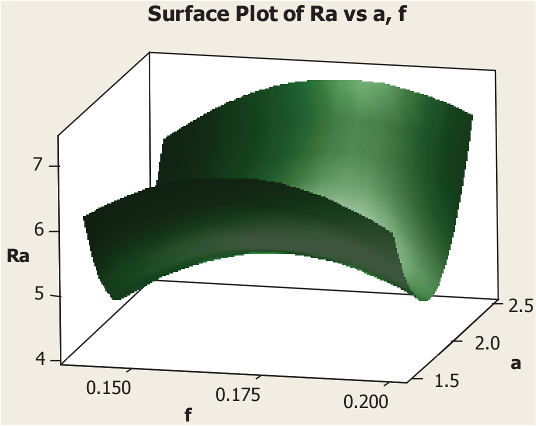

Fig. 5. 3D surface plot of the effects of the cut depth (mm) and feed rate (mm/rev) on the surface roughness

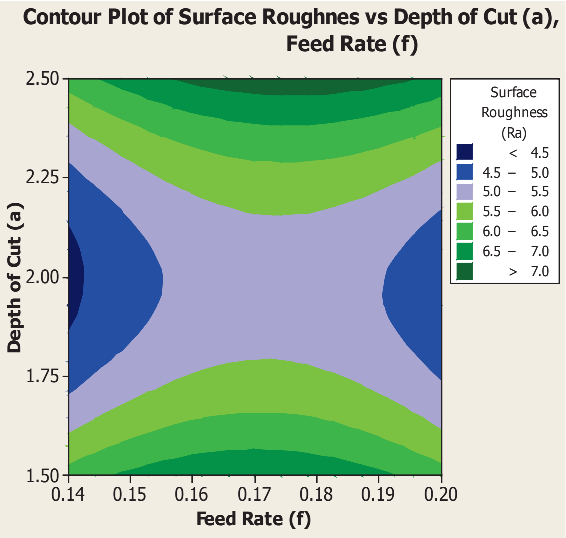

Fig. 6. Contour plot of the effects of cut depth (mm) and feed rate (mm/rev) on the surface roughness

As shown in (Fig. 7), the chart predicts that the optimum process parameter settings are 0.140 mm/rev for the feed rate; 2.0556 mm for the cut depth, and 71.8970 cSt for the AVCFs, which would result in a maximum predictable surface roughness of 2.8606 μm.

However, this result is based on the response surface regression model, and the actual measured value could be somewhat different.

Therefore, it is very strongly suggested that this setting is implemented in the future and repeated a few times to confirm or otherwise refine the result. More specifically, the effects of the feed rate and cut depth need to be investigated in depth with smaller ranges to reach a conclusion.

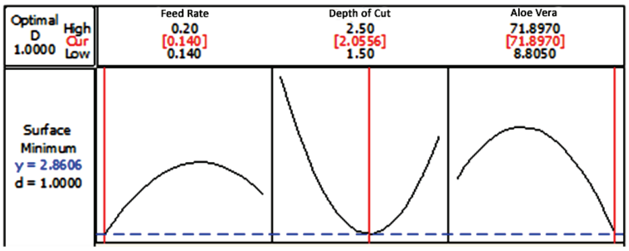

Fig. 7. Optimization chart of turning process parameters for surface roughness

From Table 9, *f*, *a* has the most significant effect on the flank wear of the turning samples. Based on the ANOVA results of Table 10, the statistical significance of each parameter can be found by comparing the mean square against an estimate of the experimental error.

Therefore, the verified model of the flank wear is shown by the following equation:

$$\begin{aligned} VB &= 0.2681 - 0.0086f + 0.0126a + 0.0081\mathrm{AVCF} - \\ &- 0.0134f^2 + 0.0004a^2 - 0.0296\mathrm{AVCF}^2 - \\ &- 0.0254fa + 0.0105f\mathrm{AVCF} + 0.0069a\mathrm{AVCF}. \end{aligned} \quad (4)$$

Table 9

Coefficients of the regression response surface models, estimated regression coefficients for flank wear

Term	Coef.	*SE* Coef.	*T*	*P*
Constant	0.268062	0.03991	6.717	0
f	–0.008578	0.01222	–0.702	0.499
a	0.012591	0.01238	1.017	0.333
AVCF	0.008077	0.0114	0.709	0.495
f^2	–0.013421	0.03663	–0.366	0.722
a^2	0.00036	0.03213	0.011	0.991
AVCF^2	–0.029593	0.05858	–0.505	0.624
fa	–0.025368	0.01254	–2.023	0.071
*f*AVCF	0.010499	0.01218	0.862	0.409
*a*AVCF	0.006962	0.01223	0.569	0.582

Table 10

Analysis of variance (ANOVA) for flank wear

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Regression	9	0.014312	0.014312	0.00159	1.1	0.436
Linear	3	0.003362	0.002731	0.00091	0.63	0.611
f	1	0.000291	0.00071	0.00071	0.49	0.499
a	1	0.003048	0.001489	0.001489	1.03	0.333
AVCF	1	0.000023	0.000723	0.000723	0.5	0.495
Square	3	0.00328	0.002215	0.000738	0.51	0.682
f^2	1	0.003025	0.000193	0.000193	0.13	0.722
a^2	1	0.000001	0.000367	0.000000	0.00	0.991
AVCF^2	1	0.000254	0.00767	0.000367	0.26	0.624
Interaction	3	0.00767	0.00589	0.002557	1.78	0.215
fa	1	0.005905	0.001071	0.00589	4.09	0.071
fAVCF	1	0.001298	0.000467	0.001071	0.74	0.409
aAVCF	1	0.000467	0.014397	0.000467	0.32	0.582
Residual Error	10	0.014397	0.00139	0.00144	–	–
Lack-of-Fit	3	0.00139	0.013007	0.000463	0.25	0.859
Pure Error	7	0.013007	0.014312	0.001858	–	–
Total	19	0.028709	–	–	–	–

Fig. 10 explained about the value of the turning process parameters with Aloe vera as the most optimum cutting fluid on the flank wear response is feed rate (0.20 mm/rev), Cut Depth (2.50 mm), and Aloe vera with Viscosity (8.8050 cSt).

In (Fig. 8), when increasing the cut depth beyond the lower level of 1.5 mm, the flank wear has shown a decreasing trend. This decrease continued until reaching a minimum flank wear at a cut depth of approximately 1.5 mm, and then it started increasing again until it reached approximately the same starting level with a cut depth of 2.5 mm. This is evident from the approximately U-shaped surface of the speed side of the 3D surface plot.

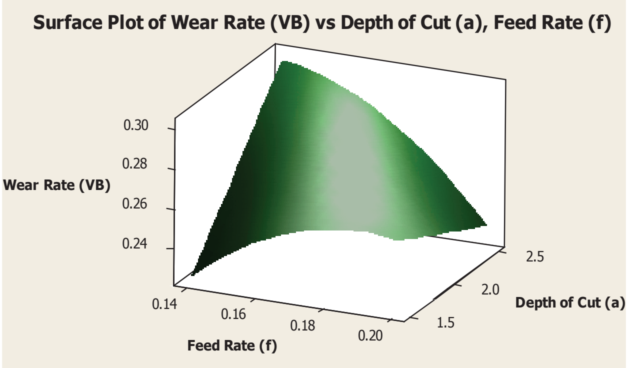

Fig. 8. 3D surface plot of the effects of cut depth (mm) and feed rate (mm/rev) on the flank wear

This is supported by the contour plot of (Fig. 9), where it is also evident from the colored green contour at 2.0 mm, which can be achieved by varying both the cut depth and feed rate.

This agrees very well with the 3D surface plot finding mentioned above. Therefore, based on the given feed rate and cut depth ranges, we can conclude that, if a high flank wear is required, then it is recommended that the feed rate is maintained at around 0.17 mm/rev.

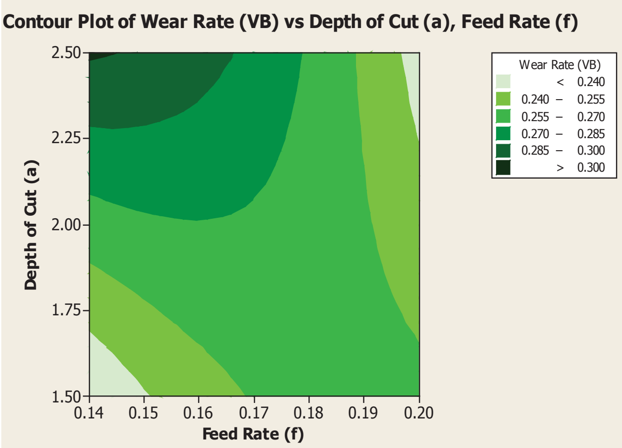

Fig. 9. Contour plot of the effects of cut depth (mm) and feed rate (mm/rev) on the flank wear

However, this finding needs to be compared with other plot findings, as it might be further refined or confirmed. As shown in (Fig. 10), the chart predicts that the optimum process parameter settings are as follows: 0.20 mm/rev for the feed rate; 2.50 mm for the cut depth, and 8.8050 cSt for the AVCFs, which would result in a maximum predictable flank wear of 0.1785 mm. These results are based on the response surface regression model, and the actual measurable value can be somewhat different.

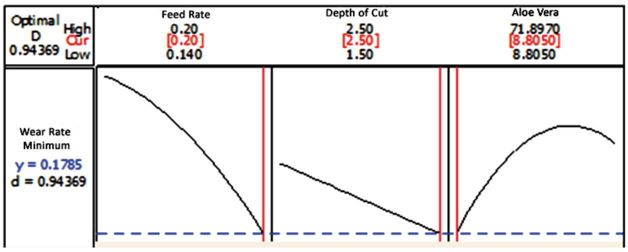

Fig. 10. Optimization chart of turning process parameters for flank wear

Thus, it is highly recommended that the setting is applied in the front and is repeated several times to confirm or improve the result. More specifically, again, the effects of the level of the feed rate and the cut depths need to be investigated in depth with a range that is smaller to obtain the optimal surface roughness and flank wear.

6. Discussion of simulation results

The use of Aloe vera cutting fluids (AVCF) has a very significant effect on the occurrence of flank wear. The advantages of this study are aloe vera cutting fluids with the chemical composition, which does not directly harm the environment and human health: there are components of Energy (1.73–2.30 Calories), Protein (0.10–0.06 gram), Fat (0.05–0.09 grams), Carbohydrate (0.30 gram), Calcium (9.92–19.920 milligrams), Iron (0.060–0.320 milligrams), Vitamin A (2.00–4.460 IU), Vitamin C (0.50–4.20 milligrams), Thiamin (0.003 to 0.040 milligrams), Riboflavin (0.001–0.002 milligrams), Niacin (0.038–0.040 milligrams), Fibers (0.30 grams), Ash (0.10 gram), Water content (99.20 gram) [13]. The limitations of this study are the range of regression equations for experimental variables used for the optimal process, contained in the equation *Ra* and the *VB* equation that can be used for estimation in this experiment. For the future study, another range of cutting process parameters can be developed.

7. Conclusions

1. The effects of the turning process parameters on the surface roughness and flank wear were examined. Square of the depth of cut (a^2) has the most significant effect on the surface roughness of the turning samples.

2. The verified model of the surface roughness is shown by the following equation:

$$\begin{aligned} Ra &= 5.2495 + 0.1536f + 0.1775a - \\ &- 0.2332\text{AVCF} - 0.7356f^2 + 1.8455a^2 - \\ &- 1.1298\text{AVCF}^2 + 0.1555fa + 0.1122f\text{AVCF} - \\ &- 0.4477a\text{AVCF}. \end{aligned}$$

AVCF and the verified model of the flank wear are shown by the following equation:

$$\begin{aligned} VB &= 0.2681 - 0.0086f + 0.0126a + \\ &+ 0.0081\text{AVCF} - 0.0134f^2 + 0.0004a^2 - \\ &- 0.0296\text{AVCF}^2 - 0.0254fa + 0.0105f\text{AVCF} + \\ &+ 0.0069a\text{AVCF}. \end{aligned}$$

3. The optimum process parameter settings of the surface roughness were 0.140 mm/rev for the feed rate; 2.0556 mm for the cut depth, and 71.8970 cSt for the AVCFs. The optimum process parameter settings on the flank wear were 0.20 mm/rev for the feed rate; 2.50 mm for the cut depth, and 8.8050 cSt for the AVCFs.

References

1. Lawal S. A., Choudhury I. A., Nukman Y. Application of vegetable oil-based metalworking fluids in machining ferrous metals – A review // International Journal of Machine Tools and Manufacture. 2012. Vol. 52, Issue 1. P. 1–12. doi: 10.1016/j.ijmachtools.2011.09.003
2. Ramana M. V., Rao K. M., Rao D. H. Effect of Process Parameters on Surface Roughness in Turning of Titanium Alloy under Different Conditions of Lubrication – Recent // Recent Advances in Robotics, Aeronautical and Mechanical Engineering. 2013. P. 83–91.
3. Sharafadeen K. K., Jamiu K. O. Performance Evaluation of Vegetable Oil-Based Cutting Fluids in Mild Steel Machining // Chemistry and Materials Research. 2013. Vol. 3, Issue 9. P. 35–45.
4. Rahim E. A., Sasahara H. A study of the effect of palm oil as MQL lubricant on high speed drilling of titanium alloys // Tribology International. 2011. Vol. 44, Issue 3. P. 309–317. doi: 10.1016/j.triboint.2010.10.032
5. Effectiveness of Minimizing Cutting Fluid Use when Turning Difficult-to-cut Alloys / Priarone P. C., Robiglio M., Settineri L., Tebaldo V. // Procedia CIRP. 2015. Vol. 29. P. 341–346. doi: 10.1016/j.procir.2015.02.006
6. Prakash D., Ramana M. V. Performance Evaluation of Different Tool in Turning of Ti-6Al-4V Alloy Under Different Coolant Condition // International Journal of Science and Research. 2013.
7. Debnath S., Reddy M. M., Yi Q. S. Environmental friendly cutting fluids and cooling techniques in machining: a review // Journal of Cleaner Production. 2014. Vol. 83. P. 33–47. doi: 10.1016/j.jclepro.2014.07.071
8. Debnath S., Reddy M. M., Yi Q. S. Influence of cutting fluid conditions and cutting parameters on surface roughness and tool wear in turning process using Taguchi method // Measurement. 2016. Vol. 78. P. 111–119. doi: 10.1016/j.measurement.2015.09.011

9. On the effects of cutting speed and cooling methodologies in grooving operation of various tempers of β-titanium alloy / Machai C., Iqbal A., Biermann D., Upmeier T., Schumann S. // Journal of Materials Processing Technology. 2013. Vol. 213, Issue 7. P. 1027–1037. doi: 10.1016/j.jmatprotec.2013.01.021
10. Wear performance of (nc-AlTiN)/(a-Si3N4) coating and (nc-AlCrN)/(a-Si3N4) coating in high-speed machining of titanium alloys under dry and minimum quantity lubrication (MQL) conditions / Liu Z., An Q., Xu J., Chen M., Han S. // Wear. 2013. Vol. 305, Issue 1-2. P. 249–259. doi: 10.1016/j.wear.2013.02.001
11. Shyha I., Gariani S., Bhatti M. Investigation of Cutting Tools and Working Conditions Effects when Cutting Ti-6al-4V using Vegetable Oil-Based Cutting Fluids // Procedia Engineering. 2015. Vol. 132. P. 577–584. doi: 10.1016/j.proeng.2015.12.535
12. Characterisation of Aloe Vera as a Cutting Fluid / Hartono P., Pratikto, Suprapto A., Irawan Y. S. // Modern Machinery Science Journal. 2017.
13. Komposisi Kimia Gel Lidah Buaya (Aloe vera L.). Ministry of Health of Republic of Indonesia, 1992.

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INFLUENCE OF THE PROPERTIES OF BLAST FURNACE SLAG ON CAST IRON HEATING AT PULVERIZED COAL INJECTION

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На двох промислових доменних печах досліджені шлаковий режим і нагрів чавуну при переході на вдування пиловугільного палива. Негативним наслідком зміненого шлакового режиму було зниження фізичного нагріву чавуну. Досліджено вплив змін у складі шлаків на в’язкість розплавів. Вивчено вплив характеристик шлакового режиму – в’язкості, основності і стехіометрії на нагрів чавуну. Суттєвий вплив шлаку на нагрів металу свідчить про необхідність врахування цього впливу при управлінні доменною плавкою і наступній переробці чавуну в сталь

Ключові слова: доменна піч, шлаковий режим, в’язкість, основність, шлак, нагрів чавуну

На двух промышленных доменных печах исследованы шлаковый режим и нагрев чугуна при переходе на вдувание пылеугольного топлива. Отрицательным следствием измененного шлакового режима явилось снижение физического нагрева чугуна. Исследовано влияние изменений в составе шлаков на вязкость расплавов. Изучено влияние характеристик шлакового режима – вязкости, основности и стехиометрии на нагрев чугуна. Существенное влияние шлака на нагрев металла свидетельствует о необходимости учета этого влияния при управлении доменной плавкой и последующем переделе чугуна в сталь

Ключевые слова: доменная печь, шлаковый режим, вязкость, основность, шлак, нагрев чугуна

1. Introduction

The transition of blast furnaces in Ukraine to the injection of pulverized coal fuel (PCF) was, as a rule, accompanied by a change in slug mode. Such a change was often characterized by a decrease in slag basicity both in relation to CaO/SiO$_2$ (C/S) and to (CaO+MgO)/SiO$_2$ (C+M)/S. A decrease in slag basicity was supposed to compensate for the negative influence of PCF on permeability of the coke head in the zone of melts flow. As a result, as shown in paper [1], there was a shift in the slag mode in the direction of formation of semi-slags, with a decrease in temperature of the produced cast iron. This decrease is known to create certain problems at subsequent converter processing of liquid cast iron. Semi-slags C/S=1.1–1.2 received their name from the specifics of hardening a sample, consisting of two parts in the fracture: glassy (C/S<1.1), characteristic of acidic, and stone-like (C/S>1.2), characteristic of the basic ones. Prior to the transition to PCF injection, operation on highly-sulfuric Donetsk coke required the formation of base slag. That is why the properties of semi-slags with less sulfur absorbing capacity were not sufficiently studied.