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Optimization Study on Experimental Results of Lubrication with Canola Oil by the Addition of MoS_2 Nanoparticles in CNC End Milling of Aluminum Alloy

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Abstract

In recent years, the use of innovative materials in high-performance applications has grown tremendously. Because of their poor machinability, these materials resolve a wide range of mechanical difficulties and need significant testing in milling. In the manufacturing business, machining is a fundamental and indispensable process. Cutting zone heat is essential for determining the quality of a work piece throughout the procedure of machining. In spite of fact that proper cutting fluids are employed in metalworking to dissipate heat, their use results in the destruction of nature and has an impact on the health of employees. Because the film layer arrangement reduces friction between the mating surfaces and therefore lowers the temperature, oil has an influence on the cutting zone, improving the surface finish in the process. Studies show that the presence of nanoparticles in cutting fluid reduces the cutting force and temperature, as well as improving the surface finish on the work piece's surface. This results in increased throughput while reducing health risks and enhancing the preferred working conditions over the traditional minimum quantity lubrication (MQL) process. Despite being a popular solid lubricant, molybdenum disulfide (MoS_2) has the potential to be an efficient medium for MQL processing is studied. As a result, research is looking into ways MoS_2 nanoparticles affect machining variables, including surface polish, and cutting zone temperature. The ideal input parameters are chosen using Response Surface Methodology (RSM) through the Box – Behnken method. This paper presents high accuracy and is suitable for the machining process, The optimal R^2 value for the model is around 0.91, Hence the design is for surface roughness and R^2 as 0.9232 for temperature is obtained.

Keywords

Molybdenum disulfide nanoparticles, Surface roughness, Temperature, Response surface methodology, Box-Behnken

Introduction

The preponderance of developed industrial countries' economies is significantly influenced by manufacturing. It is also a significant contributor to environmental pollution and greenhouse gas emissions, calling for study in the field of sustainable manufacturing. The process of machining is an essential component in production that deserves unique attention from a sustainability viewpoint since it significantly affects both the life and performance of numerous vital parts as well as the cost of production [1-3]. Because the energy used in the deformation and subsequent shear stress of the workpiece material in the series of operations in machining is primarily converted to heat, a liquid coolant is typically useful in substantial amounts to cool as well as lubricate the tool-chip interface in traditional metal cutting [4, 5]. However, these metal working fluids represent an important source of human health consequences and enormous environmental harm during both their use and disposal phases. Therefore, research into sustainable machining has mostly explored machining operations in dry conditions, optimum lubrication quantity (MQL) machining with the goal of completely eliminating or reducing the need for metal working fluids [6-8]. Goindi et al. [9] to analyze the tribological aspects of vegetable oil as a lubricant, a trial analysis was carried out. The data proves that adding additives to vegetable oil diminishes machining forces and has a substantial impact on the tribological behavior of the machining conditions, which reduces energy consumption. Pusavec et al. [10] examined cryogenic machining's surface thermal behavior. An experimental evaluation of the surface's heat transfer coefficient was performed. The ideal coolant flow rate needed for cryogenic machining was determined after doing a finite element analysis and analyzing both values. Kaynak [11] investigated the Inconel's force component and tool wear characteristics as it was being machined in a cryogenic environment. The results show a notable enhancement in the quality of a surface and a notable diminish in the characteristics of tool wear. It also demonstrates that the number of nozzles used during cryogenic machining greatly influences the forces. Su et al. [12] observed the impact of adding graphite nanoparticles to polyol-ester and vegetable oil. After assessing the oil's thermos-physical properties, the aforementioned nanofluids were made using a two-step process. The addition of nanoparticles to the two different cutting solutions resulted in a considerable decrease in cutting forces and temperature. Khan et al. [13] examined how low alloy steel turning processes were impacted by MQL. Results show that using the least amount of lubricant possible significantly reduces tool wear and improves surface smoothness and tool life. Amrita et al. [14], the impact of adding graphite nanoparticles to SAE 20W40 was investigated. After performing a stability test on the obtained nanofluid, a two-step process was used to prepare a nanofluid that is based on graphite and demonstrates good stability. The addition of nanoparticles improves the lubricating oil's tribological properties significantly. Shen et al. [15] looked into the effects of lubrication during grinding using Al_2O_3 and diamond nanoparticles in small quantities. As nanoparticles are increasingly added to cutting fluids, there is a notable enhancement in the decrease of grinding forces, temperature, as well as an advancement in the surface finish quality.

Zhang et al. [16] explored how hybrid nano fluids can be used to lubricate grinding operations in the right amount. MoS_2 and carbon nanotubes (CNTs) were added to the cutting fluids, and this resulted in a notable improvement in the diminishing of forces in grinding, temperature, and improvement in the surface finish quality. Nam et al. [17] conducted a trial study to see how nanofluids affected the micro drilling process with MQL. They took into consideration base fluids like paraffin and vegetable oil before adding diamond nanoparticles in various volume fractions between 1% and 2%. The results show that adding nanoparticles significantly reduced the thrust forces and torques. Khandekar et al. [18] examined the impact of the cutting fluid with an Al_2O_3 base during metal cutting operations. In their research, they used Servo oil, which had a 1 vol.% addition of Al_2O_3 particles, as a typical cutting fluid. The inclusion of nanoparticles significantly enhances wettability features while significantly reducing tool wear characteristics. Hegab et al. [19] looked at the outcomes of adding multi wall carbon nanotubes and Al_2O_3 to vegetable oil, the base fluid. Cutting fluids based on nanotechnology were created using a two-step process. Results show that cutting fluid based on multi wall CNTs performed better than Al_2O_3 base nanofluid. Abbas et al. [20], when turning operations were being done, optimization approaches were applied to various lubrication strategies. Results show that when compared to the other two procedures, dry and flood methods, the MQL condition on nanofluid demonstrates superior properties. Hegab et al. [21] carried out the experimental work by mixing two distinct nanoparticles, such as multiwall CNTs and Al_2O_3, with the conventional cutting fluid. Results show that when compared to the other two fluids, multiwall CNTs exhibit superior characteristics. Additionally, optimization techniques like Artificial Neural Network, ANOVA (Analysis of variance), and ANFIS were used to assess the impact of the rate of feed, nanoparticle addition, and cutting speed on flank wear, smoothness of the surface and energy consumption. Prabhu and Vinayagam [22] undertook the experimental work by combining the nanoparticles with the regular grinding fluid. In addition to the Taguchi optimization method, regression analysis and ANOVA were carried out to assess the parameters that affect the smoothness of the surface.

Vegetable oils have been the subject of a lot of literature regarding cutting fluids. Nanoparticles were, however, hardly added to conventional cutting fluids. Therefore, contemporary research has concentrated on incorporating nanoparticles into the conventional cutting fluid. In addition to those optimization techniques, input parameter effects were evaluated.

Experimentation

The RSM plans to provide us with a sense of the profile of the response surface under study by allowing us to assess association and impacts. Because they are effective designs for fitting second order polynomials to reaction surfaces, Box-Behnken method and focused central composite design are used. To evaluate the parameters, use a relatively small number of impressions. Rotatability is a reasonable concept. Reasons for choosing a reaction surface plan RSM's objectives are to boost and employ a measurement-based technique is beneficial when the proper area is uncertain before the trial is carried out. To estimate accuracy in every manner to that end, Central Composite Design - The most popular experimental designs are spherical or face-centered and Box - Behnken.

The RSM architecture allows us to analyze relationships and effects, and as a result, we can determine the (local) form of the reaction surface under examination. For an RSM issue with three variables and three levels, the Box-Behnken arrangement has the most efficient proficiency. Similar to how fewer runs are required than with a central composite scheme. 81 trial runs are anticipated for the proposed Box-Behnken configuration to display a response surface. The usual structure is followed while choosing the method variables for the test runs. Software was utilized to describe the investigation and randomly distribute the runs. Randomization makes sure that one run's conditions are independent of other runs' states and do not foretell those of later runs. Drawing precise, understandable, and accurate findings from analysis requires randomization.

Results and Discussion

The last equation with respect to real factors for temperature

The computation for the true real factors may be used to forecast the response for given values of each element. For each variable, the levels should be resolved in the initial units.

Temperature = (+424.24727 – 0.102640 Cutting Speed) + (0.021348 Size – 948.75192 Depth of Cut) – (0.826403 Feed + 0.000022 Cutting Speed * Size) + (0.176747 Cutting Speed * Depth of Cut) + (0.000287 Cutting Speed * Feed) – (0.070591 Size * Depth of Cut) + (0.000073 Size * Feed) + (0.871845 Depth of Cut * Feed) – 3.06667E-07 Cutting Speed^2 – 0.000888 Size^2 + 508.87819 Depth of Cut^2 + 0.000493 Feed^2 (1)

The difference is less than 0.2, as the predicted R^2 of 0.9232 is within 0.2 of the adjusted R^2 of 0.9380. Adequate precision measures the signal-to-noise ratio. The ideal ratio is greater than 4. The S/N ratio of 35.663 indicates a strong enough signal. When navigating the design space, this paradigm is helpful.

Figure 1 depicts a 3D plot for cutting speed vs size vs temperature which indicates the optimal region where reliable output can be achieved. Maximum temperatures are seen above the surface when the operating conditions are at high.

Temperature vs derivations from the reference point is derived in the perturbation graph as shown in figure 2. When assessing the effects of each parameter at a specific point in the design space, the perturbation plot is helpful. By changing just one component while keeping the other variables constant, the solution can be demonstrated.

Quadratic model in ANOVA

The model is implied to be significant by the regression coefficient of 87.41. Design terms are viewed as substantial when the p-value is lower than 0.0500. In this instance, key model terms include A, C, D, AC, CD, and C^2. Regression coefficients are also not significant if the value is higher than 0.0001.

The last equation in expressions of real variables for surface roughness

The genuine actual factors calculation may be used to predict the answer for given values of each element. The levels for each factor should be resolved in the initial units.

The last equation in associate with real variables

Surface Roughness = (+1.38281 – 0.000982 Cutting Speed – 0.021015 Size) + (15.73213 Depth of Cut) – (0.025776 Feed + 3.04019E) – (Cutting Speed * Size) – (0.004690 Cutting Speed * Depth of Cut) + (7.76111E-07 Cutting Speed * Feed) + (0.001717 Size * Depth of Cut) – (0.000026 Size * Feed) + (0.002740 Depth of Cut * Feed) + (6.62770E-07 Cutting Speed^2) – (2.19193E-06 Size^2) – (5.06305 Depth of Cut^2 + 0.000141 Feed^2) (2)

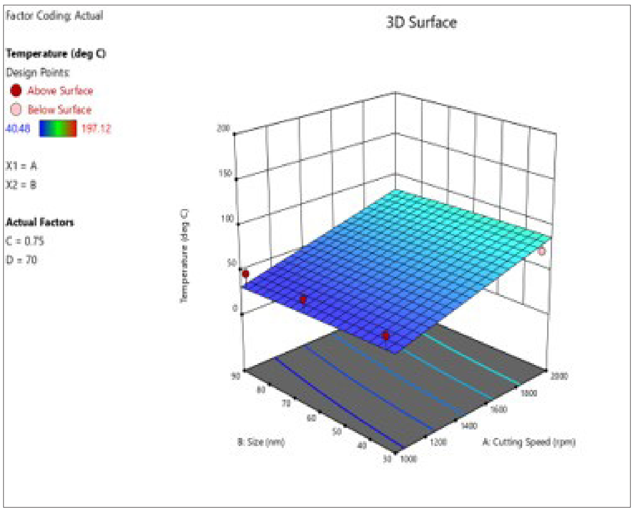

Figure 1: Plot for cutting speed vs size vs temperature.

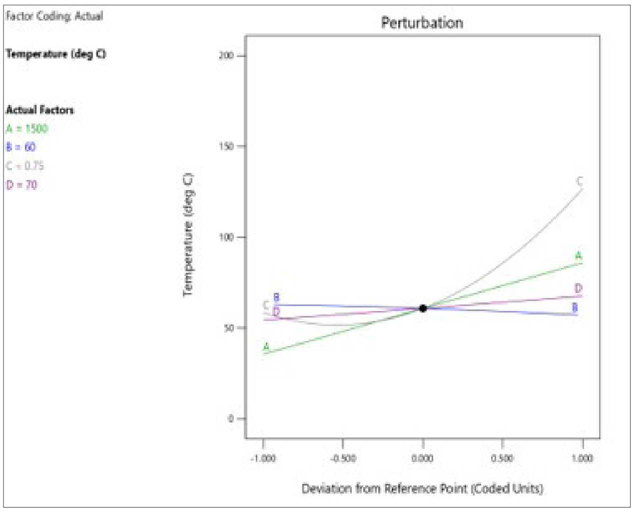

Figure 2: Temperature vs reference point as coded units.

The discrepancy between the predicted R^2 of 0.9197 and the adjusted R2 of 0.9358 is less than 0.2, which is considered to be a reasonable agreement.

With sufficient accuracy, the S/N ratio is measured. The ideal ratio is at least 4. Your ratio of 35.316 indicates that your signal is sufficiently strong. Use this model to navigate the design area.

Cutting speed in relation to size is displayed in figure 3 in 3D form. The ideal location for achieving consistent output is indicated by surface roughness. Extreme operating conditions can cause maximum temperatures to be seen above the surface.

Above the F for the perturbation, as shown in figure 4, is the plot for temperature vs derivations from the reference point. To compare each factor's influence at a particular spot in the design space, use the perturbation plot. The output can be optimized at a speed of 1500 rpm, a size of 60 nm, a depth of cut of 0.75 mm, and a feed rate of 70 mm/min.

ANOVA for quadratic model

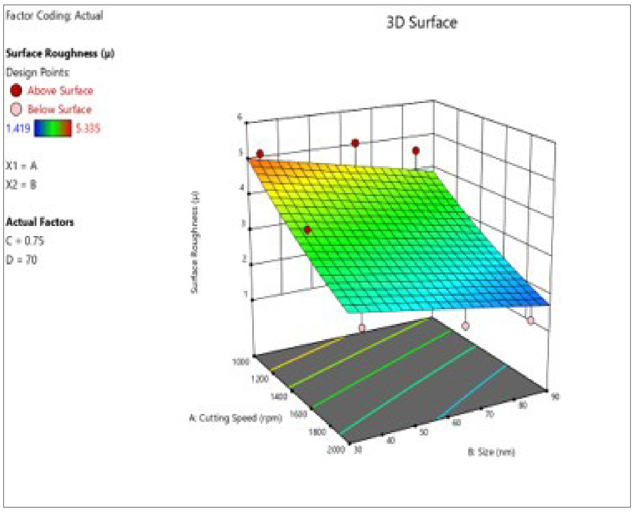

Figure 3: Plot for cutting speed vs size vs surface roughness.

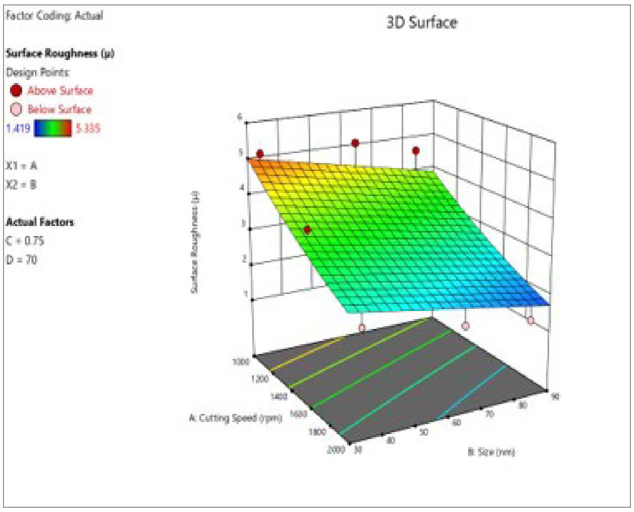

Figure 4: Surface roughness vs reference point.

The model is significant, as demonstrated by the F-value of 84.34 for it. Just 0.01 percent of the time would a noise level of this magnitude result in an F-value of this magnitude. The p-values below 0.0500 imply that the model terms are significant. The important model terms in this situation are A, B, C, D, AC, and A^2. If the values are greater than 0.0001, the C^2 model terms are not significant. Table 1 presents response: temperature. Table 2 presents response: surface roughness.

Conclusion

Initially MoS_2 based cutting fluid was prepared with vol.% of 0.5 and varying the nanoparticle size, the size of nanoparticles was studied on the parameters like temperature and surface finish. In addition, the optimization was done to the experimental data through RSM. The significant observations are drawn below.

MoS_2 nanoparticles were dispersed in lubrication oil with vol.% of 0.5 and varying the size of nanoparticles. Experimental results demonstrate that particle size below 35 nm exhibits superior surface finish and particle size below 90 nm shows decrement in surface finish.

RSM optimization was done to the experimental data by using Box-Behnken procedure to analyze the temperature and surface finish.

The difference between the adjusted R^2 of 0.9380 and the R^2 of 0.9232, according to the results, is in terms of temperature, less than 0.2. As a result, the model is significant and trustworthy. The difference between the predicted R^2 of 0.9197 and the adjusted R^2 of 0.9358 is less than 0.2. Therefore, it is

Table 1: Response: Temperature.

Source	Total squares	df	Mean square	F-value	p-value	
Model	1.362E+05	14	9726.28	87.41	< 0.0001	significant
A-Cutting speed	34174.23	1	34174.23	307.12	< 0.0001	
B-Size	394.55	1	394.55	3.55	0.0641	
C-Depth of cut	62485.10	1	62485.10	561.56	< 0.0001	
D-Feed	2354.45	1	2354.45	21.16	< 0.0001	
AB	3.31	1	3.31	0.0297	0.8636	
AC	17533.03	1	17533.03	157.57	< 0.0001	
AD	295.55	1	295.55	2.66	0.1079	
BC	8.03	1	8.03	0.0722	0.7890	
BD	0.0571	1	0.0571	0.0005	0.9820	
CD	682.57	1	682.57	6.13	0.0158	
A^2	0.1058	1	0.1058	0.0010	0.9755	
B^2	7.44	1	7.44	0.0669	0.7968	
C^2	18184.06	1	18184.06	163.42	< 0.0001	
D^2	0.7001	1	0.7001	0.0063	0.9370	
Residual	7343.91	66	111.27			
Cor Total	1.435E+05	80				

Table 2: Response: Surface roughness.

Source	Total squares	df	Mean square	F-value	p-value	
Model	100.75	14	7.20	84.34	< 0.0001	significant
A-Cutting speed	69.85	1	69.85	818.68	< 0.0001	
B-Size	9.00	1	9.00	105.44	< 0.0001	
C-Depth of cut	6.56	1	6.56	76.90	< 0.0001	
D-Feed	0.4190	1	0.4190	4.91	0.0301	
AB	0.0529	1	0.0529	0.6205	0.4337	
AC	12.33	1	12.33	144.56	< 0.0001	
AD	0.0022	1	0.0022	0.0254	0.8738	
BC	0.0041	1	0.0041	0.0478	0.8277	
BD	0.0061	1	0.0061	0.0720	0.7893	
CD	0.0067	1	0.0067	0.0789	0.7796	
A^2	0.4942	1	0.4942	5.79	0.0189	
B^2	0.0000	1	0.0000	0.0004	0.9849	
C^2	1.80	1	1.80	21.08	< 0.0001	
D^2	0.0571	1	0.0571	0.6688	0.4164	
Residual	5.63	66	0.0853			
Cor Total	106.38	80				

important to consider both criteria when deciding whether or not design is important.

The experimental results are similar to optimization data obtained from RSM.

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None.

Conflict of Interest

None.

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