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Investigations and Optimization of Turning Process Parameters on Hardness of Machined AL6061 Parts

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Abstract

Many process parameters are involved in the machining process. It is critical to achieving accurate dimensions, good surface quality, good hardness, and maximum metal removal rate.The optimization of cutting parameters for hardness in CNC turning machining with aluminum alloy 6061 material is described in this study paper. Taguchi method is employed in this study to determine the optimal cutting parameters for hardness in turning. The performance characteristics of aluminum alloy 6061 turning processes are investigated using an L-25 orthogonal array, signal-to-noise ratio, and analysis of variance byMinitab software. The present research on the turning process uses a response surface methodology to optimize the most effective process parameterson hardness, such as feed, cutting speed, and depth of cut, while taking into account surface roughness and material removal rate.

Keywords:Optimization,micro-hardness,CNC Turning operation

1. Introduction

Aluminum alloys are one of the most widely used lightweight metallic materials with good mechanical and thermal qualities. When compared to other metals, this material is quite easy to machine. Al 6061 is an aluminum alloy with outstanding mechanical qualities, corrosion resistance, and weldability, so is used in airplanes, missiles, and space, as well as screws, machine parts, and architectural applications [1]. Material removal rate, surface roughness, and hardness are the most important performance measures. It are also considered more of the most useful technological elements because of its association with many other mechanical properties such as tool life, adjustment capacity, and wear resistance. Many researchers studied a lot of cases indepth in order to discover the key factors influencing material removal rate, roughness, and hardness.**Suha *.et al*, (2013)** [2] examined the impact of cut parameters (cutting speed, feed rate, and depth of cut) on the outputs (cutting force and material removal rate (MRR)) of the AISI 52100 hard alloy steel under dry and wet condition. Turning process was carried out on CNC lathe machine. They established a sequential set of experimental runs by using central composite design (CCD) of experiment. The response surface methodology (RSM) was utilized to determine a relationship between input process parameters and output (process response). A findings showed that cutting depth has a significant effect on the components of the cutting force, while cutting speed and feeding rate had a negligible effect., on the other hand, there is a big influence of the cutting depth on the MRR.**Jayaraman and Mahesh.,(2014)**[3] investigated the impact of machining parameters (cutting speed, feed rate, and depth of cut) on responses like (surface roughness (Ra and Rz), roundness (ϕ), and material removal rate (MRR)). They conducted experiments on aluminium alloy 6061 by employing CNC turning machine under dry cutting condition and have designed experiments by using Taguchi's design of experiments. The analysis of variance (ANOVA) technique was utilized to verify the findings. From the results of experiment they observed that, feed rate is the main influencing factor on the surface roughness (Ra and Rz), roundness and MRR. **Rahul *et al*, (2014)** [4] performed regression analysis to find out the relationship between turning parameters (spindle speed, feed rate, and depth of cut) and responses (material removal rate and surface roughness). They designed experiments using L27 (3 13) taguchi's orthogonal array. They took AlMglSiCu as workpiece material which had been turned on NC controlled machine tool. They employed a non-dominated sorted genetic algorithm to find out the optimal setting of turning parameters. The best surface roughness obtained was 0.21 µm and the best MRR value obtained was 6054.12mm3. They established the reliability of genetic algorithms as one of the most accurate optimization approaches. **Chandra *et al*, (2016)** [5] studied and presented the effect of variation in turning parameters like speed, feed, depth of cut and nose radius on responses such as surface roughness, MRR, cutting time and cutting force. AL6063T6 alloy was selected as turning experiments material. Experimental design was done using taguchi L9 orthogonal array and then experiments done on CNC machine. The taguchi analysis was done using Signal to Noise Ratios to find the optimum parameters setting. From the data collected they concluded that surface roughness was minimum for cutting speed of 500 rpm and the feed rate of 0.09 mm/rev. MRR was maximum at a speed of 2000 rpm and a feed of 0.9 mm/rev.**Abhang and Hameedullah, (2011)** [6] studied the optimization of cutting tool geometry (effective radius of the cutting tool's nose) and cutting parameters (cutting speed, feed rate, and cutting depth) for given minimum values of surface roughness during the EN-31 steel turning process. Steel was machined using a heavy-duty lathe (LTM-20). They have developed empirical models for surface roughness prediction by using LINGO solver approach. a composite design was selected for experimentation design. They attained to conclusions that the optimal parameters set of the turning process corresponded to a cutting speed (189 m/min), a feed rate (0.06 mm/rev), a cutting depth (0.2mm), and a tool nose radius (1.2mm) by the lingo-solver approach.**Rao *.et al*,(2013)**[7]emphasized the importance of studying both cutting force as well as surface roughness in turning operations as a number of parameters were influenced by it such as (cutting speed, feed rate, depth of cut). They selected a hardened AISI 1050 steel as process material for turning on CNC lathe machine with tool made of ceramic. They used taguchi method (L27 design with three factors and three levels) for designing experiments. They revealed from the obtained resulted that the feed rate had significant effect on the surface roughness as well as the cutting force. Cutting speed had no significant influence on both the surface roughness and cutting force. Depth of cut had a significance effect on force of cut, while had no significant effect on surface finish. **Sathiya *et al*, (2014)** [8]conducted experimental work on EN8 steel material using CNC lathe machine. They determined the optimal turning factors (spindle speed, feed rate, and depth of cut) on surface roughness by utilizing taguchi L9 orthogonal array. Determined the signal to noise ratio of the experimental results and then conducted analysis of variance (ANOVA) to reveal significant machining variables that affect the surface roughness. They revealed based on results that the spindle speed played had a major role on surface finish. the best setting of input turning parameters was spindle speed of 100 rpm, feed rate of 0.2mm/min, and cutting depth of 4 mm. **Saravanakumar *et al*, (2018)**[9] found the optimum turning parameters (feed, speed and depth of cut) to obtain better surface finish during machining of aluminium alloy 6063 with carbon nitride insert. They conducted the experiments based on L27 orthogonal array (taguchi's method).The experimental results indicated that the feed rate was the primary factor affecting the surface roughness. Surface roughness was increased with increasing in feed rate, while roughness reduced with increasing cutting speed. Optimum levels of parameters which given minimum surface roughness were Spindle speed 1200 rpm, feed rate 0.15 mm/rev, and cutting depth 0.5mm.**Umroh *et al*, (2019)** [10] found the optimum cutting condition when high speed turning of aluminium alloy 6061 using uncoated carbide insert. Used multiple-linear regression method to develop mathematical models of responses surface roughness(Ra), flank wear (VB) and tool life(TL) in term of cutting parameters speed, feed, and depth of cut. For finding the optimum cutting conditions they used multi objective genetic algorithm (MOGA) method. The results showed that the surface roughness was more affected by feed rate while the flank wear was mostly determined by the cutting speed. The optimum cutting parameters were speed 1000m/min, feed 1.2mm/rev, and depth 1.2mm.**Senussi, (2007)**[11] concerned the optimization of the machining parameters (cutting speed, feed rate and depth of cut) and distance from the center of work piece in CNC-Turning machine, and studied their effects on the chip micro-hardness of 304-Austenitic stainless steel work piece material. He used response surface methodology (RSM) for designing a three factor with five levels in order to construct statistical models capable of accurate prediction of responses. The obtained results showed that the low value of 200 m/min and small work piece diameter of 30 mm. it revealed that high chip micro-hardness produced at high feed rate (0.2 mm/rev) and big work piece diameter (50mm).**Kosaraju.*et al*,(2011)**[12] investigated the impact of cut depth and rake angle on the cut forces generated Via an EN8 steel hollow cylindrical workpiece in three directions. The tests were conducted on a GEDEE WIELER lathe setup utilizing high speed steel (HSS) cut tools with six different angles. The total number of experiments was 30, each with a varied feeding rate but maintaining the same cut angle and depth. The findings indicated that the cut force raised as the feeding rate increased, but decreased as the rake angle increased.It is important and necessary to analyze the effects of machinability in terms of surface roughness, material removal rate, and hardness. In metallurgy, hardness is defined as a material's resistance to plastic deformation. It's also known as indentation hardness, which relates to a material's resistance to being indented. The most common type of hardness test entails pressing a sharp or rounded indenter into the material's surface while subjecting it to a significant static load. Hardness measurements can be done on a macroscale, microscale, or nanoscale, depending on the applied stresses and displacements.The aim of this study is to focus on cutting parameters (cutting speed, feed, and depth of cut) and how they affect the surface's microscopic hardness.

2. Experimental setup

The material used in this study was aluminum alloy (AL_6061) with the chemical composition shown in Table (1) and prepared the samples in standard sizes (40 mm X 100 mm).

Table (1) AL6061 Alloy work piece composition.

Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Zn%	Ti%	Al%
0.65	0.70	0.2	0.1	0.9	0.1	0.1	0.1	balance

A CNC turning lathe machine of FANUS (series Oi Mate-TC) with a diameter limit of 200 mm and a maximum length of 500 mm is used. A spindle with 45 rpm to 4000 rpm spindle speed is employed.

Figure (1) CNC turning machine of FANUS (Series oi Mate-TC).

Three turning parameters (cutting speed, feed rate, and depth of cut) with five levels (Table 2) are constructed experimentally for the machining process in this study. The five levels of cutting speed, feed rate, and cut depth are listed in Table (3).

Table(2) process parameters and their values at five levels.

Cutting parameters	Units	Notation	Limits				
			Level 1	Level 2	Level 3	Level 4	Level 5
Speed	rpm	S	500	750	1000	1250	1500
Feed rate	mm/rev	F	0.050	0.075	0.100	0.125	0.150
Depth	mm	DC	0.100	0.575	1.050	1.525	2.000

Table (3). Experimental layout using L-25 orthogonal array

Exp. No	Speed of spindle (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	500	0.050	0.100
2	500	0.075	0.575
3	500	0.100	1.050
4	500	0.125	1.525
5	500	0.150	2.000
6	750	0.050	0.575
7	750	0.075	1.050
8	750	0.100	1.525
9	750	0.125	2.000
10	750	0.150	0.100
11	1000	0.050	0.050
12	1000	0.075	1.525
13	1000	0.100	2.000
14	1000	0.125	0.100
15	1000	0.150	0.575

16	1250	0.050	1.525
17	1250	0.075	2.000
18	1250	0.100	0.100
19	1250	0.125	0.575
20	1250	0.150	1.050
21	1500	0.050	2.000
22	1500	0.075	0.100
23	1500	0.100	0.575
24	1500	0.125	1.050
25	1500	0.150	1.525

The Vickers method is the universal hardness measurement method, and it is an upgraded version of the Brinell method. It is governed by the ISO 6507 standard. To conduct this test, the material to be examined must first be prepared, then pressure put to make a mark, which is then inspected under a microscope, the diagonals measured, and an average obtained, which is the hardness level. The micro-Vickers method was employed to test hardness in this study, as indicated in Figure (2). The hardness was determined using a 300-gram load and a 10-second delay time.

Figure (2) hardness test device.

3. Results and discussion

The results of measured hardness values with the process input variables layout are shown in Table (4)

Table (4) experimental hardness measurements.

Exp. No	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	HV 1	HV 2	HV 3	Average (HV)
1	500	0.050	0.100	126	125.8	124.6	125.467
2	500	0.075	0.575	122.4	122.1	120.3	121.600
3	500	0.100	1.050	116.7	117.4	118	117.367
4	500	0.125	1.525	114.5	116	114.9	115.133
5	500	0.150	2.000	114.3	114.2	113.9	114.133
6	750	0.050	0.575	125.8	127.1	128.1	127.000

7	750	0.075	1.050	125	126	125.9	125.633
8	750	0.100	1.525	121	120.8	121.8	121.200
9	750	0.125	2.000	119.2	120	119.2	119.467
10	750	0.150	0.100	114.7	114	115.2	114.632
11	1000	0.050	1.050	128.5	128.5	129.2	128.967
12	1000	0.075	1.525	126.4	125	124.8	125.400
13	1000	0.100	2.000	124.9	123.8	124.1	124.263
14	1000	0.125	0.100	122.9	122.3	123.2	122.833
15	1000	0.150	0.575	120.9	121.9	122	121.6
16	1250	0.050	1.525	130.4	130.9	131.2	130.833
17	1250	0.075	2.000	124.6	125.1	124.4	124.700
18	1250	0.100	0.100	129.7	129	128.9	129.2
19	1250	0.125	0.575	123.7	120.9	124.4	123.000
20	1250	0.150	1.050	122.9	121.4	120.9	121.733
21	1500	0.050	2.000	130	130.2	131.2	130.461
22	1500	0.075	0.100	129.8	130	129	129.600
23	1500	0.100	0.575	126.4	126.9	127.6	126.967
24	1500	0.125	1.050	126.4	126.5	125.8	126.233
25	1500	0.150	1.525	123.1	123.8	122.8	123.233

The actual hardness findings in Table (5) are entered into the Minitab program to create mathematical equations that show how the input parameters affect the hardness as shown in equations (1) and (2).

Analyzing the final results of designed experiments was conducted by ANOVA. The equations (1) and (2) represent the resulting mathematical equations and R^2 values relate the hardness (HV) of the AL6061 alloy to the spindle speed, feed rate and depth of cut which predicted by using linear and quadratic regression analysis. The quadratic state is more acceptable than the linear state based on R^2 values for hardness . It's noting that R^2 values in the quadratic state (R^2=94.91%) are higher than those in the linear state (R^2= 90.95%) . That is mean, in the quadratic situation, the mathematical model is preferable than the linear case and given more accurate findings.

The error can be determined by comparing the actual and predicted values of those equations.The parameters F and F*F are more effective than other parameters, as shown by factor coefficients in equations (1) and (2).

It is clear that there is no significant difference between the actual and predicted hardness values as shown in Figures (3) and (4). Except for a few points that are far from the 45-degree slope line, most of the points are close to the standard line. It means that the probability of prediction, in this case, is correct and acceptable.Figure (5) illustrates the relationship between predicted and actual results with sample number for hardness, shows the extent to which the practical and theoretical results match. The difference between the actual and expected values may be due to an error in the use of the hardness measuring device or due to the surrounding conditions in the turning process.

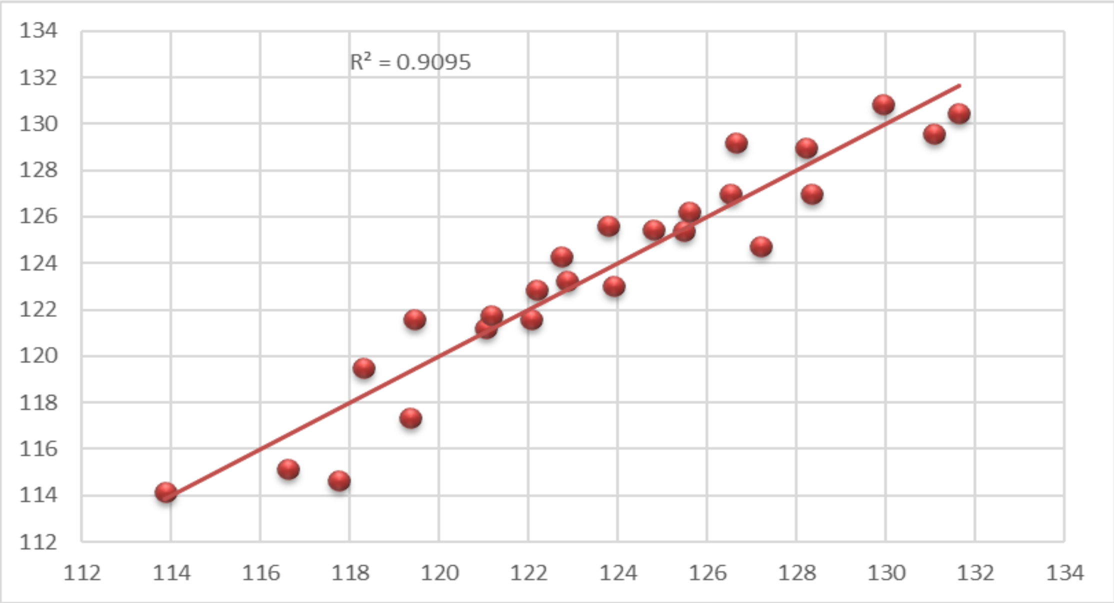

Figure (3) Relationship between predicted and actual results of hardness for linear regression.

$HV = .22 + 0.008570\,S - 92.05\,F - 0.917\,DC$……………………………..……………..(1)

R^2= 90.95%

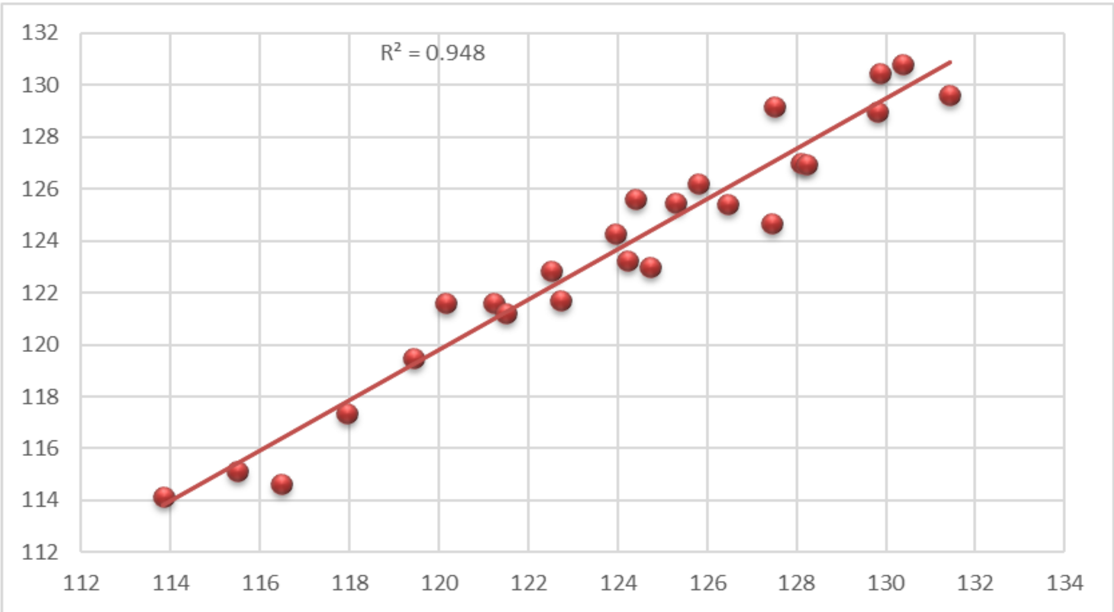

Figure (4) Relationship between predicted and actual results of hardness in quadratic regression

$HV = 129.04 + 0.01500\,S - 258.4\,F + 1.49\,DC - 0.000005\,S*S + 414\,F*F + 0.649\,DC*DC + 0.0758\,S*F - 0.00327\,S*DC$………………………………………….(2)

R^2=94.91%

Where HV, S, F, and DC represent hardness,speed in rpm, feed in mm/rev, and depth of cut in min respectively.

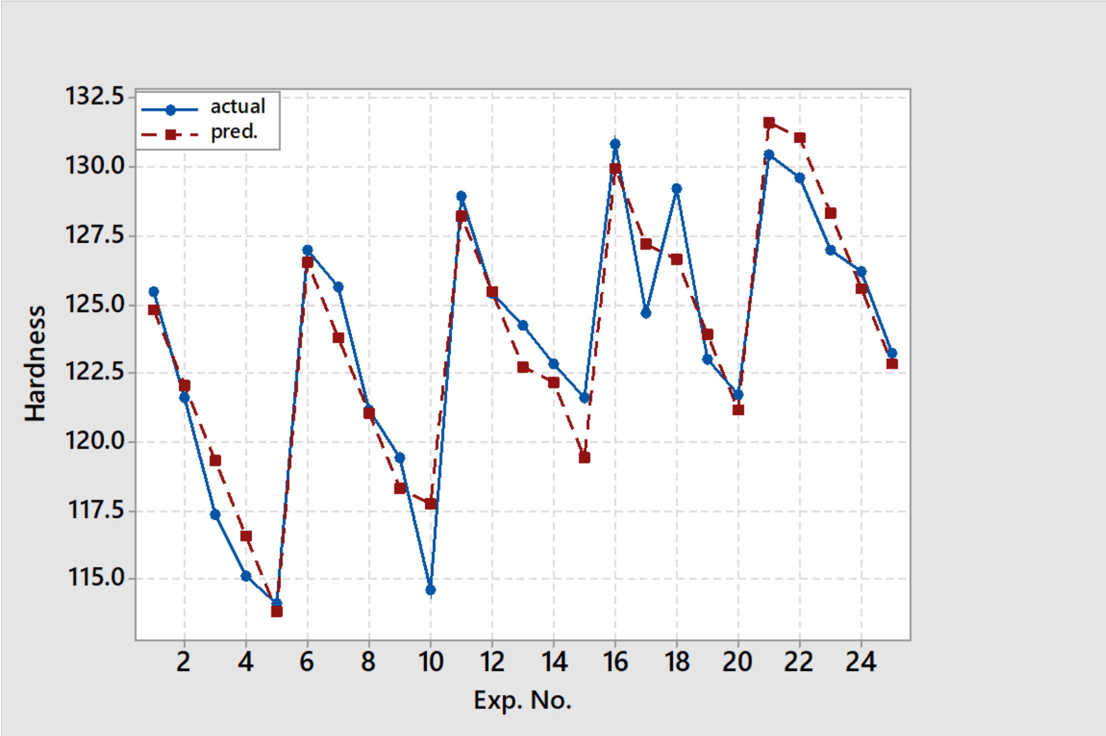

Figure (5) Relationship between predicted and actual results with experiment number for hardness (HV).

Table (5) Actual and predicted hardness at different cutting parameters.

Ex. No.	Speed	Feed	depth	Linear regression			Quadratic regression		
				Hv-actual	Hv-pred.	Error	Hv-actual	Hv- pred.	Error
1	500	0.050	0.100	125.467	124.811	0.0052	125.467	125.292	0.001
2	500	0.075	0.575	121.600	122.074	0.0038	121.600	121.212	0.003
3	500	0.100	1.050	117.367	119.337	0.0167	117.367	117.943	0.005
4	500	0.125	1.525	115.133	116.600	0.0127	115.133	115.484	0.003
5	500	0.150	2.000	114.133	113.864	0.0023	114.133	113.836	0.003
6	750	0.050	0.575	127.000	126.518	0.0037	127.000	128.096	0.009
7	750	0.075	1.050	125.633	123.781	0.0147	125.633	124.394	0.0098
8	750	0.100	1.525	121.200	121.044	0.0012	121.200	121.504	0.003
9	750	0.125	2.000	119.467	118.307	0.0097	119.467	119.424	0.0003
10	750	0.150	0.100	114.632	117.748	0.0271	114.632	116.470	0.016
11	1000	0.050	1.050	128.967	128.225	0.0057	128.967	129.792	0.006
12	1000	0.075	1.525	125.400	125.488	0.0007	125.400	126.469	0.009
13	1000	0.100	2.000	124.263	122.751	0.012	124.263	123.956	0.002
14	1000	0.125	0.100	122.833	122.192	0.005	122.833	122.512	0.003
15	1000	0.150	0.575	121.6	119.455	0.018	121.6	120.156	0.012
16	1250	0.050	1.525	130.833	129.932	0.007	130.833	130.378	0.003
17	1250	0.075	2.000	124.700	127.195	0.0200	124.700	127.434	0.022
18	1250	0.100	0.100	129.2	126.636	0.0198	129.2	127.499	0.013
19	1250	0.125	0.575	123.000	123.899	0.0073	123.000	124.711	0.014
20	1250	0.150	1.050	121.733	121.162	0.0046	121.733	122.733	0.008

21	1500	0.050	2.000	130.461	131.639	0.0090	130.461	129.856	0.005
22	1500	0.075	0.100	129.600	131.080	0.0114	129.600	131.431	0.014
23	1500	0.100	0.575	126.967	128.343	0.0108	126.967	128.211	0.0097
24	1500	0.125	1.050	126.233	125.606	0.0049	126.233	125.801	0.003
25	1500	0.150	1.525	123.233	122.869	0.0029	123.233	124.201	0.008

The ANOVA results for the hardness by comparing F-values for all input variables from Table (6), the relevance of the input parameters in (ANOVA) is determined. Hardness factors A, B, and C have F-values of (96.20), (110.98), and (3.98), respectively. As a result, the feeding rate was the most important factor impacting hardness (B, 110.98). The values in Table (7) was obtained using Numerical optimization in the Minitab program.

Table (6) Results of ANOVA for hardness.

Variance source	Degree of freedom (DOF)	Sum of squares (SS)	Mean square (MS)	F-Value	P-Value
Hardness (HV)					
Speed (A)	1	229.502	229.502	96.20	0.000
Feed (B)	1	264.781	264.781	110.98	0.000
Depth (C)	1	9.491	9.491	3.98	0.059
Error	21	50.101	2.386		
Total	24	553.875			

Table (7) The optimum cutting parameters for hardness by ANOVA.

Optimum cutting parameters	Spindle speed (rpm)	Feed rate (mm/rev)	Cutting depth (mm)
Hardness	1500	0.050	0.100

4. Conclusion

In order to construct statistical models of hardness criteria, turning tests of Al_6061 were investigated. These models were created in Minitab program using regression and response surface techniques. A regression analysis was performed to determine the relationship between input factors (cutting speed, feed rate, and depth of cut) and response (hardness) using Minitab program. hardness is observed to be reduced at lower feed rates values of 0.05 mm/rev and higher at higher feed rate values of 0.150 mm/rev.

The following conclusions can be obtained from the results and analysis:

1. Feeding rate a significant impact on the various hardness criteria investigated.

2.The predicted and experimental value was extremely close to each other, indicating that the mathematical model established might be used effectively in turning..

3.The optimal cutting parameters of Al_6061 have been discovered using response surface optimization and RSM's method: The speed is 1500 rpm, the feed is 0.05 mm/rev, and the depth of cut is 1 mm.

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