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Experimental Investigation of Turning Parameters on AA 6061-T6 Material

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Abstract. Turning is a broadly used material removal process to manufacture cylindrical products. The effects of various process parameters on turning like spindle speed, feed rate and depth of cut have been investigated to Impact on Material Removal Rate (MRR) and surface roughness (Ra) by using Response Surface Methodology. Experimental plan is performed by a Box-behenken design. The main purpose of this work is to study the effect of process parameters on Aluminium alloy AA6061-T6 surface, and to develop the mathematical model for Material removal rate and surface roughness on milling process. The quadratic model is best agreement with experimental data; finally the numerical optimization technique has been used to find out best optimum milling parameters. The optimal set of process parameters has also been predicted to maximize the MRR and minimize the surface roughness.

1. Introduction

Turning is one of the most popular machining processes and AA6061-T6 is playing vital role in modern industries. Now a day's aluminium alloy has significant role in aeronautical industries. However AA6061 is one of the important materials due to its inherent properties such as high strength to low weight ratio, good corrosion resistance, high thermal conductivity and easy machinability and formability. Still machining of aluminium alloy with turning is a difficult task due to its high speed and depth of cut. Consequently Material removal rate and Surface roughness play the most significant role in determining the productivity and the quality of a product produced with AA6061. So this work takes AA6061 aluminium alloy as a work piece material for turning [1]. With regard, to the Spindle speed, feed rate and depth of cut are considered as a predominant principal parameter in turning. Lot of researcher and investigations has been done in analyzing the cost and quality of turning. However with regard to the reduction of wastage that is caused in material removal rate has not been taken up for serious study [2]. Hence this study considers the principal parameters on material removal rate and surface roughness. Consequently, turning is one of the extensively used to make cylindrical product based contact type turning process in the order of all type of material [3]. However the MRR and surface roughness are important during turning, but the MRR are sensitive with Depth of cut, speed and the work piece material. Although, MRR is usually affected with Spindle speed and Depth of cut, the turning quality of the material depends mainly on feed rate and Speed [4, 5]. The previous research on MRR and Surface roughness had less attention for best parameter selection on aluminium alloys during All geared lathe turning. But few works were employed in the RSM, Artificial Neural Network and Fuzzy logic for predicting the parameters in turning. Thus the main aim of this work is to develop a mathematical model using RSM, to optimize turning operation using numerical optimization.



2. Experimental procedures

The experimental procedure is planned based on Box – Behnken design from the design of experiment concepts for turning operation

2.1. Machine tool

The experiments are conducted on All geared lathe machine to use of turning operation as shown in Figure.1. Based on the machine tool specification the experimental factor's range and levels are selected. The selected ranges and levels are given as an input to machine [7].

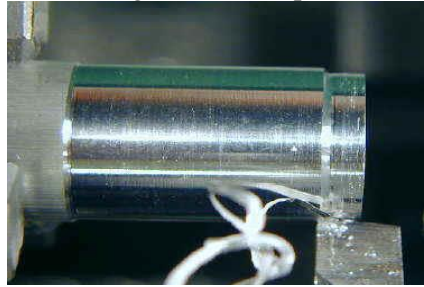


Figure 1. Turning operation

2.2. Work piece material

The work piece material considered in this work is AA6061 – T6 aluminium alloy. AA6061 – T6 is the newer material utilized in modern manufacturing industries such as Aeronautical and ship building industries due to its inherent properties. And the specimen size was round rod before machining 25mm diameter and length was 75mm

2.3. Experimental plan

The experimental work conducted based on Box-Behnken design and it requires three levels for each factor [8]. So the ranges and levels of each factor considered for this work is tabulated in table 1. The factors are Feed rate Spindle speed, and depth of cut. Turning operation carried out on work piece with 50mm length and single pass were obtained in each experimental run

2.4. Measurements of responses

The material removal rate to find out by using following relation $MRR = A_p \times v_c \times v_f$

and where A_p are Depth of cut v_c Are cutting speed and V_f are feed rate, and to measure surface roughness are to use measuring mittayo surface roughness meter.

3. Result and discussion

3.1. Response surface methodology

Response surface methodology Montgomery is a collection of mathematical and statistical techniques and to optimize this response. From the previous research the effect by Material removal rate and surface roughness are considered factors in this work were Spindle speed, feed rate and depth of cut on Material removal rate and surface roughness. In order to matamatical model the relations between these variables, the response surface methodology was assumed [9].

$$R = b_0 + \sum_{i=1}^2 b_i X_i + \sum_{i=1}^2 b_{ii} X_{ii}^2 + \sum_{i=1}^2 \sum_{j=1, (i < j)}^2 b_{ij} X_i X_j + \varepsilon \quad (1)$$

Where X_1 , X_2 and X_3 represented the spindle speed, feed rate and depth of cut respectively, X_i^2 and $X_i X_j$, the squares and the interaction terms of these factors, the constants b , the regression coefficients of these parameters and ϵ , the experimental error.

Table 1 . Experimental plan

S.No	Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	MRR (mm ³ /min)	Surface roughness (μm)
1	945	1.25	2.5	0.187	1.657
2	945	1.25	2.5	0.198	1.786
3	945	1.5	3	0.187	1.654
4	840	1.25	2	0.165	1.354
5	945	1.25	2.5	0.197	1.765
6	945	1.25	2.5	0.1765	1.897
7	1050	1.25	2	0.259	0.987
8	945	1	3	0.1909	1.987
9	840	1.5	2.5	0.249	1.678
10	1050	1.5	2.5	0.1892	0.879
11	840	1	2.5	0.1987	1.789
12	945	1.25	2.5	0.21	1.987
13	945	1	2	0.11	1.786
14	840	1.25	3	0.166	1.987
15	1050	1.25	3	0.259	0.9087
16	1050	1	2.5	0.173	0.9078
17	945	1.5	2	0.231	1.23

3.2. Analysis of variance (ANOVA)

ANOVA is the statistical method it is used to calculate the size of the variation in data set [10]. The main elements of ANOVA table are sum of squares, mean square, source of variance, DOF, F ratio and the probability associated with the F ratio. The source of variance deals with parameters that are called factors (Spindle speed, Feed rate and Depth of cut).

The ANOVA Table 2 shows that the models are significant and the F-value are 11.50 implies. And low signal noise. The probability values are less than 0.0500 indicate model terms are significant. In this case Speed and feed are significant model terms. And the R^2 and Adj R^2 values are 0.9718 and 0.8891. so that model are find the design space.

The ANOVA Table 3 shows that the models are significant and the F-value are 13.86 implies. And low signal noise. The probability values are less than 0.0500 indicate model terms are significant. In this case Speed and feed are significant model terms. And the R^2 and Adj R^2 values are 0.946 and 0.8786. so that model are find the design space.

Table 2. ANOVA table for Material Removal Rate

Source	Sum of		Mean		F Value	p-value
	Squares	df	Square			
Model	0.0219	12	0.0018		11.4989	0.0152
A	0.0092	1	0.0092		57.6116	0.0016
B	0.0021	1	0.0021		13.0778	0.0224
C	0.0002	1	0.0002		1.2631	0.3240
AB	0.0006	1	0.0006		3.7354	0.1254
AC	0.0001	1	0.0001		0.7338	0.4399
BC	0.0039	1	0.0039		24.5360	0.0077
A ²	0.0018	1	0.0018		11.2958	0.0283
B ²	0.0060	1	0.0060		37.9791	0.0035
C ²	0.0000	1	0.0000		0.1168	0.7497
A ² B	0.0003	1	0.0003		2.0135	0.2289
A ² C	0.0002	1	0.0002		1.0135	0.3710
AB ²	0.0093	1	0.0093		58.3959	0.0016
Error	0.0006	4	0.0002			
Total	0.0226	16				

Table 3. ANOVA table for Surface roughness

Source	Sum of		Mean		F Value	p-value
	Squares	Df	Square			
Model	2.5355	9	0.2817		13.8648	0.0011
A	1.8347	1	1.8347		90.2965	< 0.0001
B	0.0717	1	0.0717		3.5299	0.1023
C	0.0152	1	0.0152		0.7500	0.4152
AB	0.0017	1	0.0017		0.0831	0.7814
AC	0.1265	1	0.1265		6.2251	0.0413
BC	0.0124	1	0.0124		0.6119	0.4597
A ²	0.7786	1	0.7786		38.3175	0.0004
B ²	0.0236	1	0.0236		1.1637	0.3165
C ²	0.0264	1	0.0264		1.3002	0.2917
Residual	0.1422	7	0.0203			
Lack of Fit	0.0777	3	0.0259		1.6044	0.3216
Error	0.0646	4	0.0161			
Total	2.6777	16				

3.3. Response surface models

Response Surface model, are to predict the Material removal rate and Surface roughness values, is developed using RSM. The cubic mathematical models have been developed to predict the Material removal rate and surface roughness. The developed mathematical models for AA 6061-T6 are showed equations 2-3

$$MRR = +23.81 - 0.0374 \times A - 27.1 \times B - 1.07 \times C + 0.034 \times A \times B + 3.07e^{-3} \times A \times C - 0.249 \times B \times C + 1.1e^{-5} \times A^2 + 9.6 \times B^2 - 8.4e^{-3} \times C^2 - 4.58e^{-6} \times A^2 \times B - 1.63e^{-6} \times A^2 \times C - 0.01 \times A \times B^2 \quad (2)$$

$$Ra = -39.128 + 0.077 \times A + 0.628 \times B + 4.522 \times C + 7.8e^{-4} \times A \times B - 3.38e^{-3} \times A \times C + 0.446 \times B \times C - 3.9e^{-5} \times A^2 - 1.1 \times B^2 - 0.3168 \times C^2 \quad (3)$$

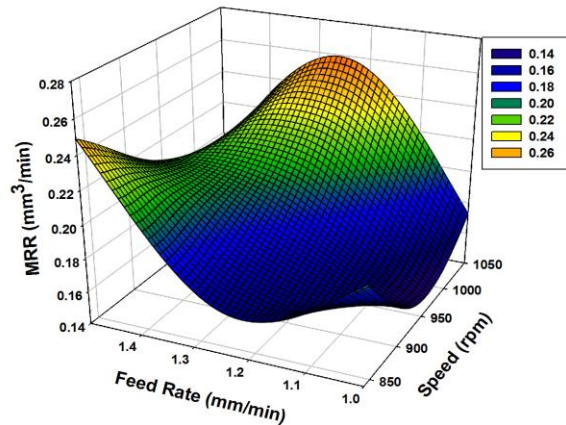


Figure 2. Effect Speed and Feed rate on MRR

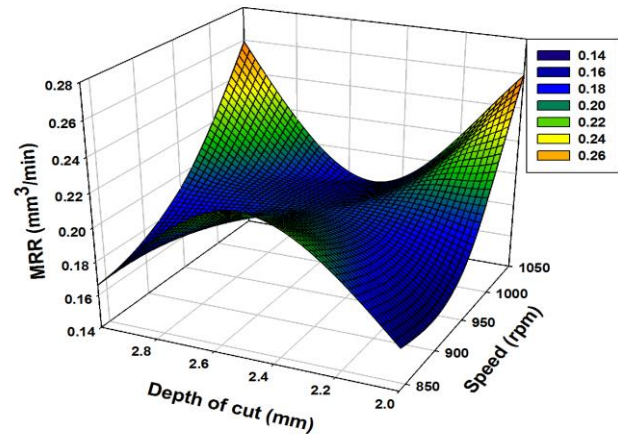


Figure 3. Effect Speed and Depth of cut on MRR

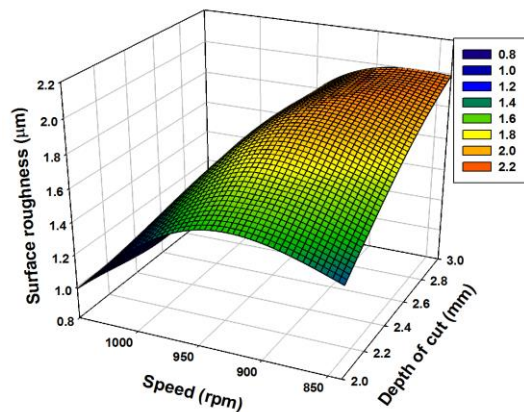


Figure 4. Effect Speed and Depth of cut on Surface roughness

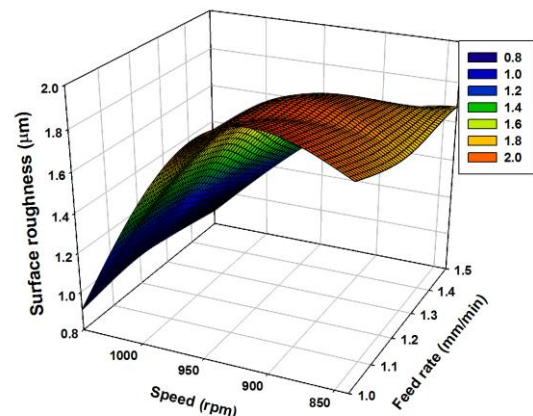


Figure 5. Effect Speed and Feed rate on Surface roughness

The figure.2 express, firstly the Material removal rate is low (range from 0.14 to 0.16 mm³/min) at mid level of the Feed rate (1.2-1.25 mm/min) and Spindle speed at 950 rpm. MRR is gradually increased with respect to increase the feed rate and low speed. The MRR is maximum (0.26 mm³/min) at the high level of spindle speed (1000-1060 rpm). The fig.3 suggests, at constant spindle speed of 850 rpm for increasing depth of cut the MRR increases towards the mid-point and then starts decreases towards the end point. At constant depth of cut 2mm for increasing spindle speed the MRR increases. At maximum spindle speed and Depth of cut the MRR are maximum.

The Figure.4 shows, initially the surface roughness is low (1μm) at high level of the spindle speed (1000-1050 rpm) while low level of depth of cut 2mm. Surface roughness is gradually increased with respect to increase the depth of cut and decrease the spindle speed. Surface roughness is maximum

(2.1 μm) at the high level of Depth of cut (2.6-3mm). From the Figure 5 shows that all level of feed rate at high spindle speed to achieve low surface roughness. Minimum spindle speeds at all level of feed rate (1-1.5 mm/min) the surface roughness's are high.

3.4 . Validation of experimental results

To predict and validate the improvement in Material removal rate and surface roughness for turning of Aluminium alloy AA6061-T6 with respect to the chosen initial parameter setting, confirmation tests are used.

Figure. 6 –7 shows the validation of experimental results for the Material removal rate and surface roughness respectively for AA 6061-T6. Thus, the response equations for Material removal rate and surface roughness to develop through response surface methodology can be used to predict the MRR and surface roughness for any combination of turning parameters within the experimentation range.

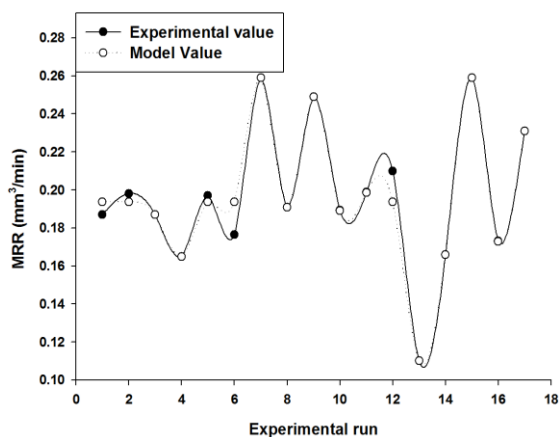


Figure 6. MRR on Experimental vs model value

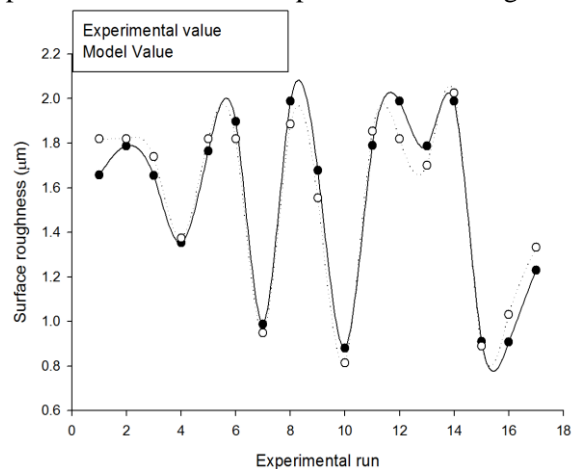


Figure 7. Surface roughness on Experimental vs model value

4. Optimization

Optimization can be defined as the process of finding the situations that give the maximum or minimum value of a function. Optimization, in its broadest sense, can be applied to solve any engineering problem [11]. In this work optimization of turning parameters on MRR and Surface roughness, The MRR and Surface roughness is a quality, but this work is tried to achieve same turning parameters at AA 6061-T6. The numerical optimization was used; the multi response optimization is solved desirability approach by using design expert software. The numerical optimization is set the goal as shown in Table 4 to minimize the response to achieve high quality. Table 5 shows the optimized value for MRR and Surface roughness of input parameters to the corresponding response value. the finally to predicted the response value Material removal rate 0.2926 mm³/min and Surface roughness 0.3879 μm has been achieved. And the Figure 8 shows overlay plot drawn between the Spindle speed and feed rate the Depth of cut at 2mm. These ranges of graphical optimization result shows on the figure 8. the shaded area on the overlay plot regions are to be achieved for proposed criteria and select the optimal turning parameters.

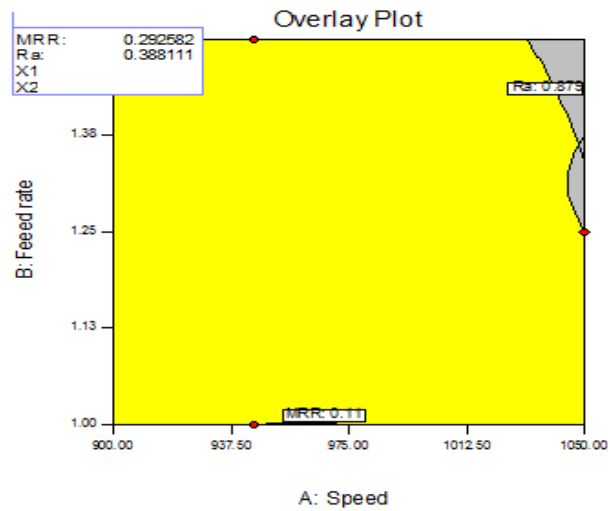


Figure 8. Over lay plot shows the region of optimal cutting condition

Table 4. Criteria for Numerical optimization

Name	Goal	Lower Limit	Upper Limit
Speed (rpm)	maximize	900	1100
Feed rate (mm/min)	is in range	1	1.5
Depth of cut (mm)	minimize	2	3
MRR (mm ³ /min)	maximize	0.11	0.259
Ra (μm)	minimize	0.879	1.987

Table 5. optimization result for cutting conditions

Si. No	Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	MRR (mm ³ /min)	Ra (μm)
1	1100	1.16	2	0.2926	0.3879
2	1100	1.17	2	0.2995	0.3807
3	1100	1.13	2	0.2817	0.3964
4	1100	1.2	2	0.3080	0.3678
5	1100	1.41	2	0.2842	0.2130
6	1100	1.31	2	0.3147	0.2989
7	1100	1.37	2	0.2996	0.2477
8	1100	1.34	2	0.3092	0.2758
9	1100	1.11	2	0.2702	0.4030
10	1100	1.19	2	0.3049	0.3731

5. Conclusion

This work to findings the experimental Investigation of the effect of Spindle speed, Feed rate and Depth of cut on the MRR and Surface roughness in Turning for AA 6061-T6 the following conclusions are made

- The ANOVA tables of the MRR and Surface roughness shows the models are significant the probability value is < 0.0001
- The numerical optimization is carried out the combinations of process parameters are identified to achieve the maximum MRR and minimum surface roughness.
- The Depth of cut plays a dominant role in the turning conditions of AA 6061-T6. This indicates that the high Spindle speed and minimum Depth of cut to achieve small surface roughness and Maximum MRR.
- Response graph can be used graphically for selecting the turning parameters and providing the preferred MRR and surface roughness values.
- The minimum Surface roughness and maximum MRR is obtained from the study were $0.3879 \mu\text{m}$ and 0.2926 mm , when the process parameters such as spindle speed, feed rate and depth of cut were maintained at 1100 rpm, 1.16 mm/min, and 2mm. It is possible to obtain the minimum Surface roughness and MRR using the above values of process parameters.

6. References

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