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Optimization of Material Removal Rate and Surface Roughness Measurement of Al 6061 by Turning

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ABSTRACT

Industrial revolution of manufacturing industry, the machining operations is backbone of every industry. Industry involved in material removing operation is greatly focusing on choosing right and optimized machining process. Machining is a part of manufacturing. In every industry machining is done to remove the excess material from the work piece to get desired shape and size with accuracy This study is an attempt to review and optimize of turning of Al 6061 and influence/effect of machining parameters viz. speed, feed and depth of cut, on the surface roughness of Aluminium 6061.

Keywords- Machining, optimization, Aluminium 6061.

Introduction

Machining is a systematic process that involves the gradual removal of metal from a workpiece. This encompasses various techniques, including metal cutting with single-point cutting tools and grinding using abrasive wheels. These operations are carried out using specialized machines known as machine tools, with the goal of achieving the desired shape, size, and surface finish on the workpiece. Machining is an integral part of the broader manufacturing process, serving as a means to eliminate excess material from the workpiece in order to achieve precise shapes and sizes with accuracy. It is particularly crucial in situations where stringent tolerances on dimensions and surface finishes are required.[1] The fundamental principle underlying machining is to create the desired surface by orchestrating suitable relative motion between the cutting tool and the workpiece. The cutting edge of the tool effectively removes a layer of material from the workpiece, resulting in what is known as a chip. This relative motion between the tool and the workpiece can be achieved through two primary methods: one involves keeping the workpiece stationary while imparting motion to the cutting tool, while the other involves keeping the cutting tool stationary while moving the workpiece. These movements are facilitated by the use of specialized machines known as machine tools, which enable the generation of the necessary relative motion.[2]

Machining Process

Numerous machining processes are employed to shape materials, and these processes can be broadly classified into two categories as outlined below:

Single-point machining

This category includes operations such as turning, boring, grooving, facing, and similar techniques. In single-point machining, a single cutting tool engages with the workpiece to create the desired shape and dimensions.[3]

Multiple-point machining

This category encompasses operations like drilling, milling, grinding, and other similar processes. Unlike single-point machining, multiple-point machining involves the use of multiple cutting tools to achieve the desired outcomes.The decision to select a specific machining process is typically based on several factors, including the product's requirements, the experience and expertise of operators and engineers, and the technical demands of the task at hand. These considerations collectively guide the choice of machining process to ensure optimal results.

Cutting fluid

Cutting fluid, a specialized coolant and lubricant, is specifically formulated for use in metalworking and machining operations. This fluid plays a crucial role in facilitating various machining processes. Cutting fluids come in a range of types, including oils, emulsions of oil and water, pastes, gels, and even air or other gases. They can be formulated using various raw materials such as petroleum distillates, animal fats, plant oils, water, air, and other ingredients. Depending on the specific context and the type of cutting fluid under consideration, it may be referred to by different names, including cutting fluid, cutting oil, cutting compound, coolant, or lubricant. The choice of terminology often depends on the application and the specific characteristics of the cutting fluid being used. In most metalworking and machining processes, the use of cutting fluid provides significant benefits. However, the necessity and effectiveness of cutting fluid depend on the material of the workpiece. Notably, there are exceptions to this rule, such as when machining materials like cast iron and brass, where dry machining (without the use of cutting fluid) is more suitable and effective.[4-5]

Beneficial effects of cutting fluids are summarized below:

- Reduction of cutting force and energy consumption.
- Increase in tool life due to cooling effects.
- Improved surface finish and accuracy of size.
- Easy removal of the chip.
- Less distortion of the work piece due to cooling effect.
- Corrosion prevention on work piece.
- Lubrication of machine tool slide ways.

Literature review

Based on the findings of previous literature surveys, it is apparent that researchers have conducted studies on turning processes. However, there remains a substantial need for further applied research in this domain to fully explore the effective applications of this process in the field of material machining. Notable past research endeavors in this area are summarized briefly below. Here, you can list specific examples of past research work related to turning processes and machining of materials that have been carried out by previous researchers.

Jitendra Thakkar et al. in 2014, the investigation centered around examining the impact of various process parameters, namely cutting speed, feed rate, and depth of cut, on distinct response variables. It was noted that the optimization of surface roughness posed a multi-factor, multi-objective optimization challenge. In their study, they employed a Design of Experiment (DOE) approach, specifically utilizing a full factorial design. This methodology enabled the generation of 27 test specimens through straight turning operations conducted on SS410 material.Furthermore, the researchers computed the Material Removal Rate (MRR) using relevant equations and specialized software. The obtained MRR values were then compared. The study also entailed the collection of data related to surface roughness, which subsequently played a pivotal role in the optimization process. The study's findings underscored the complexity of optimizing surface roughness, necessitating a systematic approach that accounts for the intricate interplay of multiple factors and objectives.[6]

K. Pavan Kumar Reddy et al. in 2014, the focus was on investigating the intricate aspects of multi-objective optimization within the turning process on AISI1045 steel material. Specifically, the researchers employed a CNMG cutting tool and aimed to identify the optimal combination of process parameters that would result in the lowest surface roughness while simultaneously achieving the highest Material Removal Rate (MRR). To address the challenge of multi-objective optimization, the study employed a combined approach of Grey Relational Analysis (GRA) and the Taguchi method. Recognizing the inherent limitation of the traditional Taguchi method in dealing with multi-objective optimization problems, the researchers integrated the Grey relation theory to enhance its capabilities. To achieve their objectives, nine experimental runs were executed using the Orthogonal array design of the Taguchi method. These experiments were conducted within the defined experimental domain, focusing on optimizing the objective functions. Additionally, the study employed Analysis of Variance (ANOVA) to quantitatively evaluate the significance of the factors influencing the overall quality characteristics of the cutting process. The results obtained through the optimal parametric combination were further validated through additional experimental runs. This research highlighted the value of combining advanced techniques like GRA with traditional methodologies like Taguchi to effectively address the complexities of multi-objective optimization in machining processes.[7]

S.V. Alagarsamy et al. in 2014, the focus was on investigating cutting parameters for Aluminum Alloy 7075 using a CNC machine. The research aimed to present an effective approach for optimizing turning parameters using a combination of Taguchi's method and Response Surface Methodology (RSM). The researchers explored the utilization of Taguchi's technique to minimize surface roughness and simultaneously maximize the Material Removal Rate (MRR) during the machining process of Aluminum Alloy 7075. They specifically used a TNMG 115 100 tungsten carbide tool for the experiments. The study employed a series of experiments based on Taguchi's L27 orthogonal array, and the Minitab-16 statistical software was used to generate the experimental design.Three key machining parameters were selected as process variables for the investigation: Cutting Speed, Feed Rate, and Depth of Cut. The research employed the orthogonal array and Signal-to-Noise (S/N) ratio, along with Analysis of Variance (ANOVA), to comprehensively analyze the performance characteristics of the CNC turning operation. The goal was to determine the optimal values of the process parameters that would result in the desired performance characteristics. The Taguchi Design of Experiment was used to identify the optimal process parameter values that would lead to the desired outcomes. Additionally, a second-order mathematical model was developed using Response Surface Methodology, which provided a deeper understanding of the relationships between the cutting parameters and the performance characteristics. Overall, this research showcased the integration of Taguchi's method and Response Surface Methodology to optimize cutting parameters and enhance the performance of CNC turning operations, particularly in the context of machining Aluminum Alloy 7075.[8]

Methodology

Keeping in view the proposed objectives, the following methodology have been adopted to meet the set objectives in turning of Al 6061.

1. Turning of Al 6061rod has been performed on a CNC machine using CNMG 120408 EN-TM insert for various combinations of cutting parameters.
2. Taguchi based Design of experiments has been used to find out optimum number of experiments to be conducted to achieve the said objectives.
3. Surface roughness of machined surface has been measured using a surface analyzer during experimentation.
4. Material removal rate has been evaluated using high precision balance by weighing samples before and after experimentation.
5. Analysis has been carried out using analysis of variance (ANOVA). The significance of the regression model and significant model term i.e spindle speed, feed and depth of cut are clearly highlighted
6. Models have been developed to correlate output variables such material removal rate and surface roughness, with the input variables i.e. spindle speed, feed and depth of cut.

Experimental setup

The respective Experiments were performed on the CNC turning machine named Super jobbers 400 of the ACE MICROMATICS available at MACHINING WORKSHOP in industrial area Chandigarh. The different experiments for the Turning and the facing operations were carried on the Aluminium 6061 alloy. The workpiece were taken to the workshop and the machining is carried out for the experiments. The machining results were noted and entered into the data sheet for the further analysis. After the machining process the Surface roughness has been measured by the Mitutoyo surftest SJ-201P.Specimens are prepared by cutting the rod of Aluminium 6061 having the diameter of 25.4 mm in the length of 55mm.Aluminum rod was cut into pieces with help of power hacksaw. Experiments are performed in a sequence as per design of experiments.

Material removal rate

The material removal rate, MRR, can be defined as the volume of material removed divided by the machining time. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the workpiece. The S/N ratios for MRR are calculated as given in Equation 6.1. Taguchi method is used to analysis the result of response of machining parameter for larger is better criteria.

$\eta = -10 \log_{10} . [\, 1/n \quad \sum 1/ y_i^2 \quad]$; i = 1,2,--------n; - - - - - - - - - - - - Eqn. 1

i = 1

Where η denotes the S/N ratios calculated from observed values, y_i represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment in L_9 OA is conducted. The analysis of variances for the factors clearly indicates that the depth of cut is not important for influencing MRR and Speed and feed are the most influencing factors for MRR. The case of MRR, it is “Larger is better”, so from this table it is clearly define that speed is the most important factor then feed and last is depth of cut. Table 1and 2 shows the metal removal rate and analysis of variance during machining. Larger value of material removal rate was found at parametric combination of Speed =3000, Feed= 0.4 mm/rev, Depth of cut =0.3 mm.

Table 1 Experimental results and S/N ratio for Material removal rate.

S.NO	Speed (RPM)	Feed (mm/rev)	DOC (mm)	MRR (mm^3/min)	S/N Ratio MRR
1	1000	0.2	0.1	476.3949	53.5593
2	1000	0.3	0.3	637.5887	56.0908
3	1000	0.4	0.5	661.2173	56.4069
4	2000	0.2	0.3	2409.926	67.6401
5	2000	0.3	0.5	2954.787	69.4105
6	2000	0.4	0.1	3766.526	71.5188
7	3000	0.2	0.5	3408.067	70.6502
8	3000	0.3	0.1	4130.38	72.3198
9	3000	0.4	0.3	5336.661	74.5454

Table 1 shows the ANOVA for material removal rate. From ANOVA analysis is observed that speed is the most significant factor with percentage contribution of 88.176%, Feed has 8.44% contribution and Depth of cut has the least effect on material removal rate and has 1.691% contribution.

Table 2 ANOVA for Material removal rate

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Speed (RPM)	2	21259530	21259530	10629765	51.17	0.019	88.176
Feed(mm/rev)	2	2027731	2027731	1013866	4.88	0.170	8.410
DOC (mm)	2	407825	407825	203912	0.98	0.505	1.691
Error	2	415505	415505	207753			1.723
Total	8	24110591					

Fig. 1 shows the S/N response graph for material removal rate , it is concluded that optimal parametric combinations for maximum material removal rate is $A_3B_3C_2$

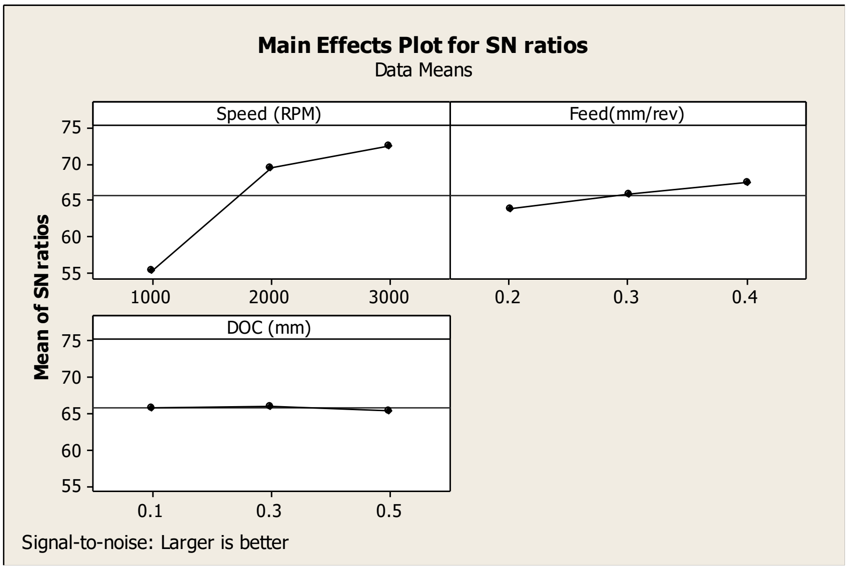

Fig. 1 S/N response graph for MRR

Fig. 2 shows the effect of feed (mm/rev) and depth of cut (mm) on material removal rate (mm^3/min). In Fig. 7, along X-axis "0.2" to "0.4" represents variation in feed with an increment of 0.1 mm/rev and along Y-axis "0.1" to "0.3" represents variation in depth of cut with an increment of 0.1 mm. From the Fig. 2, it is clear that material removal rate of workpiece increases with increase in feed (mm/rev). It is also observed that material removal rate increases with increase in depth of cut. From the graph it is clear that at higher setting value of feed and higher setting values of depth of cut, the material removal is maximum.

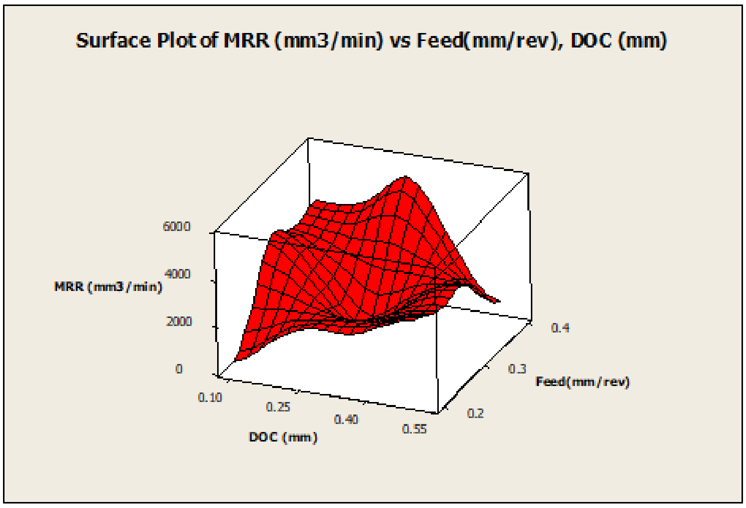

Fig. 2 Effect of depth of cut and feed on MRR

Fig. 3 shows the effect of depth of cut (mm) and speed on material removal rate (mm^3/min). In Fig. 3, along X-axis "1000" to "3000" represents variation in speed with an increment of 1000 rpm and along Y-axis "0.1" to "0.5" represents variation in depth of cut with an increment of 0.1 mm. From the Fig. 3, it is clear that material removal rate of workpiece increases with increase in depth of cut (mm). It is also observed that material removal rate increases with increase in speed. From the graph it is clear that at higher setting value of depth of cut and higher setting values of speed, the material removal rate is maximum.

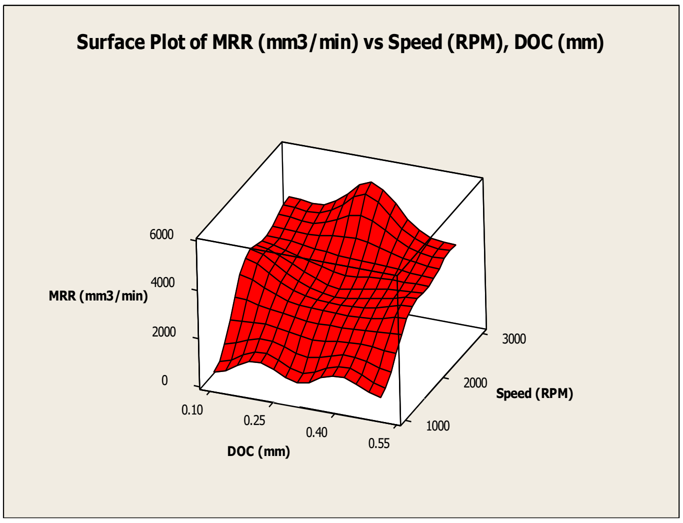

Fig. 3 Effect of depth of cut and speed on MRR

Fig. 4 shows the effect of feed (mm/rev) and speed on material removal rate (mm^3/min). In Fig. 4, along X-axis “1000” to “3000” represents variation in speed with an increment of 1000 rpm and along Y-axis “0.2” to “0.4” represents variation in feed with an increment of 0.1 mm/rev. From the Fig. 4, it is clear that material removal rate of workpiece increases with increase in feed (mm/rev). It is also observed that material removal rate increases with increase in speed. From the graph it is clear that at higher setting value of feed and higher setting values of speed, the material removal is maximum.

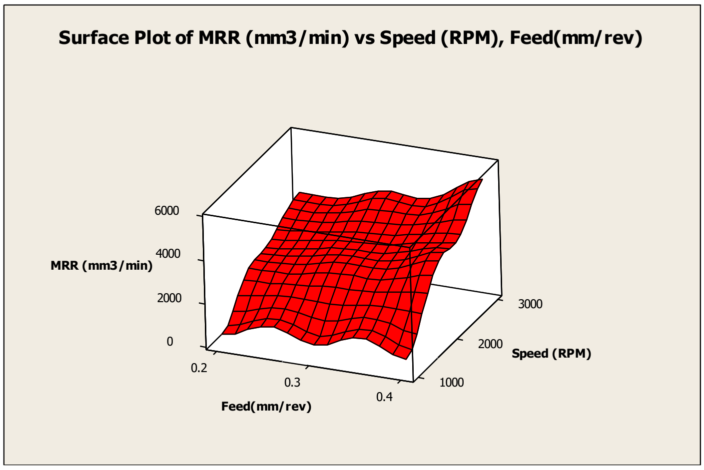

Fig. 4 Effect of speed and feed on MRR

Surface roughness

Surface texture is one of the important factors that control friction and transfer layer formation during sliding. Considerable efforts have been made to study the influence of surface texture on friction and wear during sliding conditions. Surface textures can be isotropic or anisotropic. Sometimes, stick-slip friction phenomena can be observed during sliding depending on surface texture. Each manufacturing process (such as the many kinds of machining) produces a surface texture. The process is usually optimized to ensure that the resulting texture is usable. If necessary, an additional process will be added to modify the initial texture. The table 3 shows the results of the surface. After the experimentation, the best parametric combination for the better surface quality was found to be at Speed =1000, Feed= 0.2 mm/rev, Depth of cut =0.1 mm.

Table 3 Experimental results and S/N ratio for Surface roughness.

S.NO	Speed (RPM)	Feed (mm/rev)	DOC (mm)	Ra (µm)	S/N ratio Ra
1	1000	0.2	0.1	1.52602	-3.6712
2	1000	0.3	0.3	2.65566	-8.4834
3	1000	0.4	0.5	3.407562	-10.6489

4	2000	0.2	0.3	1.931454	-5.7177
5	2000	0.3	0.5	3.45045	-10.7575
6	2000	0.4	0.1	3.404398	-10.6408
7	3000	0.2	0.5	2.786902	-8.9024
8	3000	0.3	0.1	3.56142	-11.0325
9	3000	0.4	0.3	4.763741	-13.5590

Table 4 shows the ANOVA for surface roughness. From ANOVA analysis is observed that feed is the most significant factor with percentage contribution of 65.65%, speed has 28.87% contribution and Depth of cut has the least effect on surface roughness and has 3.23% contribution.

Table 4 ANOVA analysis for surface roughness

Source	DOF	Seq SS	Adj SS	Adj MS	F	P	%age
Speed (RPM)	2	2.1392	2.1392	1.0696	12.78	.073	28.87
Feed(mm/rev)	2	4.8647	4.8647	2.4323	29.07	0.033	65.65
DOC (mm)	2	0.2393	0.2393	0.1197	1.43	0.411	3.23
Error	2	0.1673	0.1673	0.0837			2.26
Total	8	7.4105					

Fig. 5 shows the S/N response graph for surface roughness, it is concluded that optimal parametric combinations for minimum surface roughness is $A_1B_1C_1$

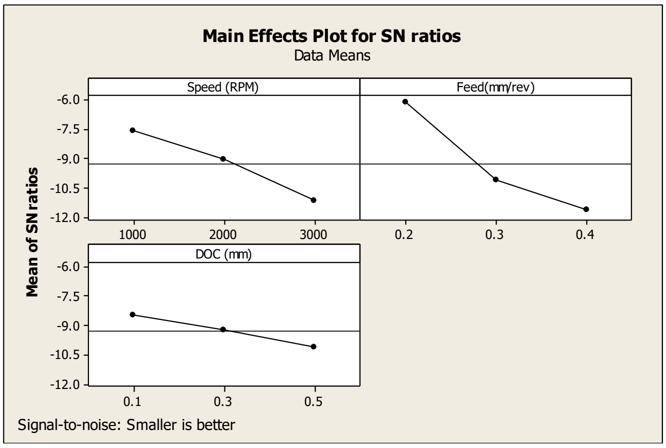

Fig. 5 S/N ratio plot for surface roughness

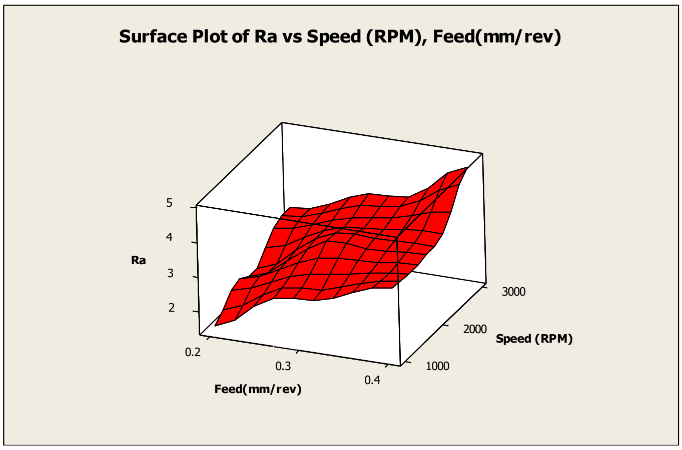

Fig. 6: Effect of speed and feed on surface roughness

Fig. 6 shows the effect of feed (mm/rev) and speed on surface roughness (µm). In Fig. 6, along X-axis "1000" to "3000" represents variation in speed with an increment of 1000 rpm and along Y-axis "0.2" to "0.4" represents variation in feed with an increment of 0.1 mm/rev. From the Fig.6, it is clear that roughness of workpiece increases with increase in feed (mm/rev). It is also observed that roughness increases with increase in speed. From the graph it is clear that at higher setting value of feed and higher setting values of speed, the surface roughness is maximum. It is also observed that surface roughness of workpiece is minimum when the speed and feed rate have minimum values.

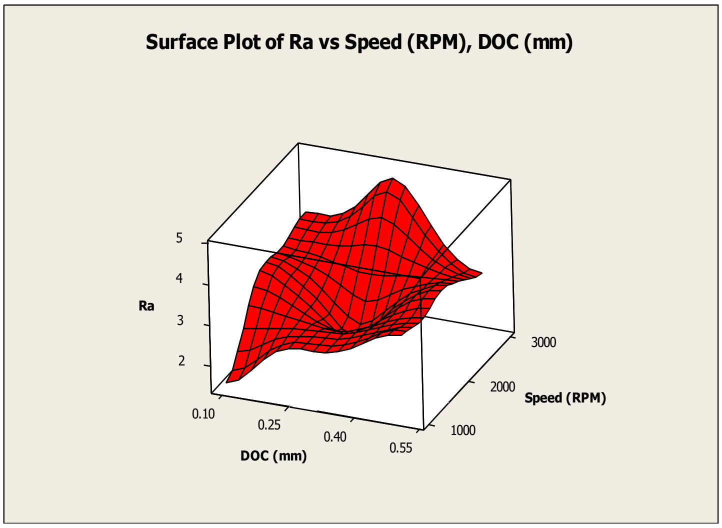

Fig. 7: Effect of speed and depth of cut on surface roughness

Fig. 7 shows the effect of depth of cut (mm) and speed on surface roughness (µm). In Fig. 7, along X-axis “1000” to “3000” represents variation in speed with an increment of 1000 rpm and along Y-axis “0.2” to “0.4” represents variation in depth of cut with an increment of 0.1 mm. From the Fig. 7, it is clear that roughness of workpiece increases with increase in depth of cut (mm). It is also observed that roughness increases with increase in speed. From the graph it is clear that at higher setting value of depth of cut and higher setting values of speed, the surface roughness is maximum. It is also observed that surface roughness of workpiece is minimum when the speed and depth of cut have minimum values.

Fig. 7 shows the effect of feed (mm/rev) and depth of cut (mm) surface roughness (µm). In Fig. 7, along X-axis “0.2” to “0.4” represents variation in feed with an increment of 0.1 mm/rev and along Y-axis “0.1” to “0.3” represents variation in depth of cut with an increment of 0.1 mm. From the Fig. 7, it is clear that surface roughness of workpiece increases with increase in feed (mm/rev). It is also observed surface roughness increases with increase in depth of cut. From the graph it is clear that at higher setting value of feed and higher setting values of depth of cut, the surface roughness is maximum. It is also observed that minimum surface roughness is achieved at minimal values of depth of cut and feed.

Mathematical models

Mathematical model and comparison graph for material removal rate

Y_{MRR} = 881.707 - 1.74424 X_1 - 9895.86 X_2 + 416.781 X_3 - 2.27037e-005 X_1^2 - 2521 X_2^2 - 65.9168 X_3^2 + 16.6701 $X_1 \times X_2$ - 0.0268944 $X_1 \times X_3$ + 461.195 $X_3 \times X_2$ ------------Eqn. 2

Where, X_1 = Speed (rpm), X_2 = Feed (mm/rev) and X_3 = Depth of Cut (mm)

Fig. 8 shows the graphical representation of the mathematical model(2) and experimental results obtained from 27 sets of experimental investigation. From the Fig., it is concluded that the mathematical modelhas a good agreement with the experimental values.

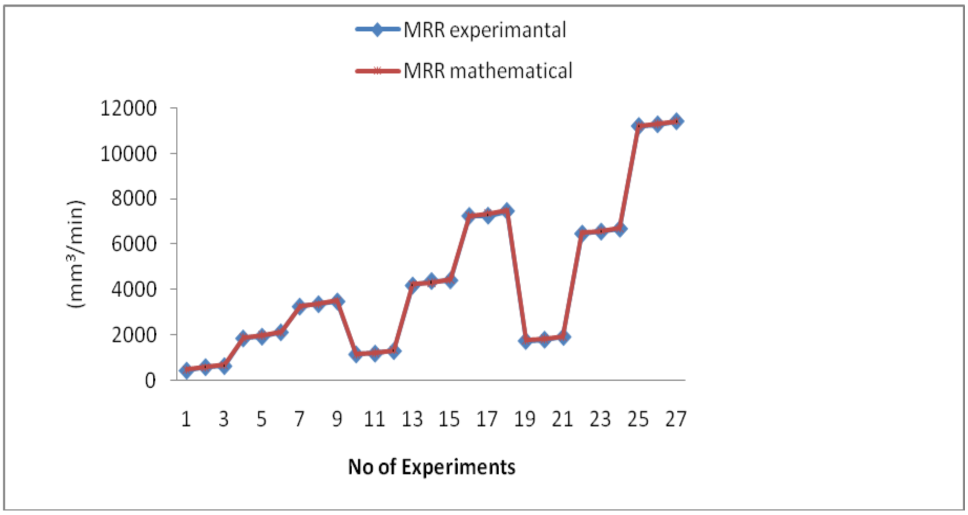

Fig.8 Comparison of MRR for aluminum 6063 by experiment and mathematical model

Mathematical model and comparison graph for surface roughness

$$Y_{Ra} = 5.51057 - 0.00462022\, X_1 + 13.6935\, X_2 - 3.78549\, X_3 + 6.3209e\text{-}007\, X_1^2 - 24.8125\, X_2^{\,2} - 3.109\, X_3^2 + 0.0037233\, X_1 \times X_2 + 0.00231777\, X_1 \times X_3 \quad \text{Eqn. 3}$$

Where, X_1 = Speed (rpm), X_2 = Feed (mm/rev) andX_3= Depth of Cut (mm)

Fig. 8 shows the graphical representation of the mathematical model(3) and experimental results obtained from 27 sets of experimental investigation. From the Fig., it is concluded that the mathematical modelhas a good agreement with the experimental values.

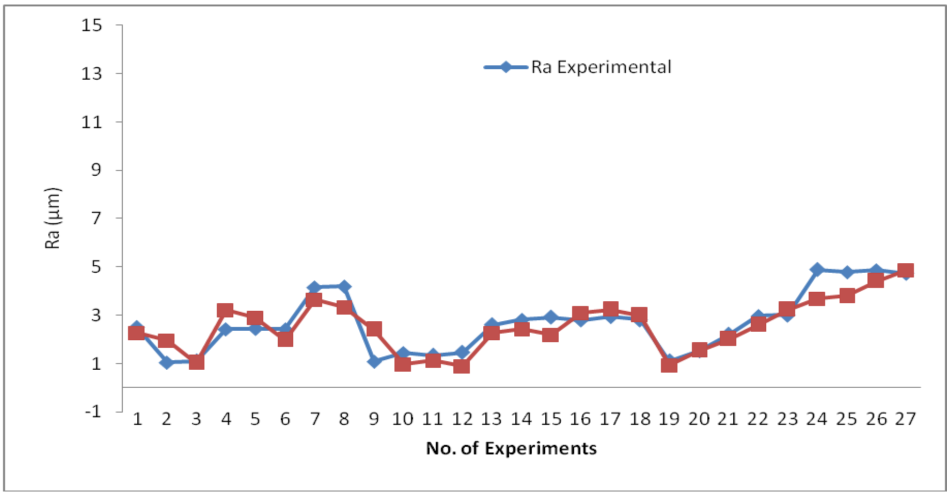

Fig. 9 Comparison of surface roughness for aluminum 6063 by experiment and mathematical model

CONCLUSIONS

On the basis of the experimental results during machining on Aluminium 6063 utilizing the CNC machine and thereafter discussion on the investigated results, the following conclusions are drawn as listed below.

1. The feed has a most significant effect on surface roughness with 65.65 % contribution. The contribution of speed on surface roughness is 28.87 %.
2. The speed has a most significant effect on Material removal rate with 88.176% contribution, feed has 8.41% contribution.
3. For maximum material removal rate, the optimal parametric combination is $A_3B_2C_3$ i.e. material removal rate is maximum at the parametric combination of 3000 rpm spindle speed, .0.4 mm/rev feed and 0.3 mm depth of cut.
4. For minimum surface roughness , the optimal parametric combination is $A_1B_1C_1$ i.e. material removal rate is maximum at the parametric combination of 1000 rpm spindle speed, 0.2 mm/rev feed and 0.1 mm depth of cut.
5. Regression based developed mathematical model shows good agreement with the experimental results obtained for surface roughness and material removal rate.

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