Modeling and Optimization of Turning Parameters during Machining of AA6061 composite using RSM Box-Behnken Design

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Abstract. CNC machines are currently dominating the machining manufacturing industries. Machining parameters that assume a significant job are shaft speed, feed rate and depth of cut in choosing quality machining. Point of present examination is to locate the ideal turning parameters, and its impact on response during machining of aluminium alloy 6061 with carbide embeds tool. Three process parameters have been adopted to obtain maximum material removal rate and better surface finish using response surface methodology RSM. Box-Behnken with three factors and their level that consists 15 runs has been used for experimentation and analysis purpose. The mathematical model has been made to anticipate the responses against chosen parameters. The 3D plot shows the interaction effect between input parameters and output. Results indicate that feed is the most influential factor for surface roughness and depth of cut have a significant contribution in material removal. Further, optimize the parameters for minimum surface roughness and maximum MRR, the optimum parameters are 1800 rpm spindle speed, 0.15mm/rev feed rate and 1.5mm depth of cut. The experimental results were analyzed utilizing Design Expert 12 solver.

1. Introduction

Turning is a significant machining measure which is utilized to decrease the external diameter of a rotating cylindrical workpiece [1]. The process has been regarded as quite advantageous over other manufacturing processes such as casting, forging and rolling in producing surface finish. With the advent of modern materials, the conventional machining processes became incapable of achieving the required product’s quality, the use of computer numerical control (CNC) machine grown in various fields. In the current industrial scenario, many times the primary manufacturing operations are still worked out on conventional machines, but whenever precision and accuracy are required then, CNC machines are being used. In machining operations, surface characteristics play a vital role and are considered as a prime indicator of quality work. As pointed by many authors [2,3], the better surface characteristics improve aesthetic aspect, corrosion resistance, fatigue strength and creep life of the product. Thus, the improved surface characteristic is vital to achieving the required product quality.

When aluminium is alloyed with magnesium and silicon, it finds its wide applications in the fabrication of the lightweight structure. The alloys compositions provide the material with medium to high strength and very good corrosion resistance. It has good toughness, extrusions and welding properties. With adequate heat treatments process, its mechanical properties such as hardness, strength, and toughness can be further improved. Attributable to its high strength to weight apportion aluminium 6061 alloys has its applications in aircraft structure, Military, Aerospace, construction, Automotive, Equipment, Containers, Packing and Soft Bearing. Seeing its broad applications, in the current investigation, aluminium composite 6061 has been taken as work material.

Surface texture and material removal rate (MRR) have been considered as two vital characteristics to evaluate the machine tools performance [3]. Thus, in this exploration work, these two boundaries (surface roughness of machined parts and MRR) were considered as the output response and shaft speed, feed rate and depth of cut during machining were taken as input factors. Figure 1 presents the succession of activities associated with this investigation. The following section presents a literature review on the various process parameters with respects to different materials and alloys combinations.
2. Literature review

Machining is a cycle by which a crude material is changed over into wanted shape and size in the wake of eliminating the additional material. When contrasted with other assembling strategies, assortments of math highlights are conceivable with exactness and accuracy by CNC machining. Asilturk et al. [4] examined the impact of feed, the profundity of cut, workpiece upheaval utilizing
Taguchi and reaction surface philosophy on AISI 304 work material. This examination results that feed is the main boundaries for surface harshness with a commitment of 85.5% in the model. Utilizing RSM, it likewise built up a numerical model to discover the connection between information and yield boundaries. Aggarwal et al. [5] endeavoured to streamline the CNC turning boundaries for AISI P-20 apparatus steel utilizing attractive quality capacities. In this exploration cutting pace, feed, the profundity of cut and nose range were chosen as turning boundaries and surface harshness, device life, cutting power, power utilization was taken as the quality trademark. With the assistance of the 3D plot, the examination results show that lower benefit of cutting pace, feed and profundity through high estimation of nose span is alluring for high estimation of attractive quality. Gupta et al. [6] proposed single and multi-yield advancement of CNC turning on AISI P-20 instrument steel for experimentation. The examination result discovered Cryogenic climate conditions as generally great in cutting activity. Given test, results in creators presumed that under Cryogenic climate conditions apparatus life increments and surface unpleasantness, cutting power, power devouring diminishes. Likewise, Tian-Syung Lan et al. [7] utilized different slicing boundaries for going and for enhancing the CNC turning boundaries against the harshness and MRR utilizing serious Taguchi streamlining procedure. Nataraj et al. [8] proposed the enhancement of CNC turning on mixture metal lattice composite against the control boundaries, for example, cutting rate, feed and profundity of cut against the yield reaction surface completion of machined parts and vibration during machining. The outcome infers that feed has a significant impact on vibration and profundity of cut, cutting pace is a principal supporter in surface hardness. In another examination, Kumar et al. [9] endeavoured to examine the turning boundaries against surface completion on AA6063 with carbon nitride embed. It establishes that speed and feed are backwards concerning their effect on surface harshness. Further, it shows that with speed up surface harshness diminishes while with increment in feed surface unpleasantness increments. It likewise found that feed is the major impacting boundaries of surface unpleasantness of machined parts.

In another investigation, Tzenga et al. [10,11] have utilized Gray social examination (GRA) to upgrade the turning activity boundaries on SKD 11 as a work material. ANOVA investigation was done to locate the critical factor for reaction trademark. From GRA it was presumed that profundity of cut is more powerful boundaries for typical harshness, though, cutting pace discovered having a more substantial effect on most extreme unpleasantness. Vijaya et al. [12] endeavoured to streamline the multi-pass turning boundaries by utilizing ant colony system (AC) and hereditary calculation (GA). From this examination, it was inferred that AC framework proposed predominant arrangement than GA. Salih Guvercin et al. [13] utilized Box-Behnken configuration joined with RSM to enhance the boundaries of CNC on AISI 1040. In this investigation, results found that feed rate is the main boundaries for surface unpleasantness all the while cutting rate shows the least impact on surface harshness. In light of the above writing survey, in the current examination, writers chose axle speed, feed and profundity of cut on AA6061 as cycle boundaries.

The examination suggested Box-Behnken Design as it decreases the quantity of preliminary trial for investigation and displaying. Further, it very well may be savvy, and a couple of quantities of analysts have chipped away at this. From writing, it was seen that there is an expanding request to alter and upgrade the cycle boundaries to accomplish great surface completion and material evacuation for the serious market.

Nomenclature used in this article.

\[
\begin{align*}
Ra &= \text{Arithmetic mean surface roughness in } \mu\text{m} \\
Rz &= \text{Distance between highest peak to deepest valley in } \mu\text{m} \\
A &= \text{spindle speed (rpm)} \\
B &= \text{feed rate (mm/rev)} \\
C &= \text{depth of cut (mm)}
\end{align*}
\]

3. Experimental work

A turning operation required a machine or lathe (to rotate the component at high speed), fixture (generally attached with a machine to hold the workpiece) and a cutting tool (to perform the actual cutting operation). The material used in this investigation was AA6061 aluminium alloy which was pre-shaped. Based on excellent properties and application in various manufacturing industries
aluminium alloy 6061 was selected for experimentation. [14] The chemical compositions and mechanical properties of work metal are presented in table 1, 2. The entire cutting operation used a single point carbide insert tool. During operation, cutting tool fed into the rotating workpiece which cut away the material in the form of chip and produced the required dimension.

**Table 1. Work material chemical composition**

|   | Mg  | Si  | Fe  | Cu  | Cr  | Mn  | Zn  | Ti  | Al  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|   | 0.89| 0.73| 0.45| 0.31| 0.16| 0.09| 0.09| 0.06| Balance |

**Table 2. Base metal mechanical properties**

| Ultimate tensile strength | Yield strength | % elongation | Vicker hardness number (HV) | Reduction in cross-section area |
|---------------------------|----------------|-------------|-----------------------------|-------------------------------|
| 352MPa                    | 301MPa         | 17.6        | 105                         | 14.24                         |

In this study, the aluminium alloy of 30mm diameter and 100 mm length were machined based on different parameters combination given by Design of experiment. The machining operations carried out on CNC machine, as shown in Figure 2.

From the literature and the previous work, the important parameters had identified, and large no of trial experiments had carried out to find out the working range and level of selected parameters on CNC Lathe. The experiments were conducted on the JOBBER XL CNC lathe designed by Ace designer ltd. The spindle power of machines used is 7.5 KW, and the range of the speed is 40-4000 rpm. CNMG 120408-M3 650A is carbide insert or tip tool manufactured by SECO used for all machining operations. After the machining surface finish was measured in terms of Ra and Rz by the potable surface roughness measurement instrument designed by Mitutoyo SJ-210, as shown in Figure 3. Generally, in the case of the machined surface, both Ra and Rz factors are taking into consideration practically. Ra and Rz values were measured at measuring the speed of stylus tip 0.25mm/sec. and return speed 1mm/sec. Measuring force was applied 0.75mN, and the selected stylus profile consists of tip radius 2µm, tip angle 60º.

### 3.1. Design of Experiment

Response surface methodology is a collection of mathematical or numerical and statistical technique. It is used to analyze the complicated problems where two or more independent variables influence the dependent response. Simultaneously, RSM optimizes the parameters for optimum response. In this study, all experiments have been carried out according to BBD. It involves 15 experiments at different independent variables combination. The experimental parameters and its level involved in machining are shown in table 3, in the form of actual and coded value. The upper limit of the factors is coded as +1, the lower limit is -1, and intermediate level is 0.
Table 3. Machining parameters and level

| Parameters             | Lower level(-1) | Intermediate level(0) | Higher level(+1) |
|------------------------|------------------|-----------------------|------------------|
| Spindle speed (rpm)    | 1200             | 1500                  | 1800             |
| Feed rate (mm/rev)     | 0.15             | 0.20                  | 0.25             |
| Depth of cut(mm)       | 0.5              | 1.0                   | 1.5              |

4. Result and Discussions

Turning activities were directed for the arrangement of various input boundaries as per RSM, BBD. An Aggregate of 15 runs was directed, as per the plan of the experiment. Surface roughness was estimated of the machined surface, and the material removal rate (MRR) has been determined for all combination and qualities were recorded and introduced in table 4.

Table 4. Plan of Analysis utilizing RSM Box-Behnken Design and test result

| Standard order | Run | N(rpm) | f (mm/rev.) | d(mm) | Ra(µm) | Rz(µm) | MRR(mm³/min) |
|----------------|-----|--------|-------------|-------|--------|--------|--------------|
| 9              | 1   | 1500   | 0.15        | 0.5   | 2.476  | 12.894 | 10602.8      |
| 7              | 2   | 1200   | 0.2         | 1.5   | 2.898  | 15.549 | 33929.2      |
| 15             | 3   | 1500   | 0.2         | 1.0   | 3.746  | 19.251 | 28274.3      |
| 14             | 4   | 1500   | 0.2         | 1.0   | 3.501  | 17.583 | 28274.3      |
| 12             | 5   | 1500   | 0.25        | 1.5   | 3.972  | 19.764 | 53014.3      |
| 1              | 6   | 1200   | 0.15        | 1.0   | 2.454  | 13.395 | 16964.6      |
| 8              | 7   | 1800   | 0.2         | 1.5   | 3.221  | 15.189 | 50893.8      |
| 10             | 8   | 1500   | 0.25        | 0.5   | 4.161  | 17.976 | 17671.4      |
| 13             | 9   | 1500   | 0.2         | 1.0   | 3.152  | 16.49  | 28274.3      |
| 4              | 10  | 1800   | 0.25        | 1.0   | 4.746  | 19.96  | 42411.5      |
| 3              | 11  | 1200   | 0.25        | 1.0   | 4.108  | 19.326 | 28274.3      |
| 6              | 12  | 1800   | 0.2         | 0.5   | 3.043  | 14.639 | 16964.6      |
| 5              | 13  | 1200   | 0.2         | 0.5   | 2.674  | 11.982 | 11309.7      |
| 11             | 14  | 1500   | 0.15        | 1.5   | 2.737  | 17.381 | 31808.6      |
| 2              | 15  | 1800   | 0.15        | 1.0   | 2.424  | 11.748 | 25446.9      |

4.1 Evolution of mathematical models

A statistical technique was used to explain the behaviour of selected boundaries during the machining operation. The regression model has been developed by using a statistical technique to represent the behaviour of a dependent variable with respect to independent variables. The second-order regression model established the relationship between each of output parameters as surface roughness and material removal rate with input boundaries like speed, feed rate and depth of cut. The following mathematical model has been evolved by using Design Expert statistical software based on the experimental data in terms of the actual factor.

1. \[ \text{Ra} = 3.46633 + 0.1625A + 0.862B + 0.05925C + 0.167AB -0.0115AC -0.1125BC -0.205417A^2 + 0.172083B^2 -0.301917C^2 \]
2. \[ \text{Rz} = 17.7747 + 0.1605A + 2.701B + 1.299C + 0.57025AB -0.75425AC -0.67475BC -2.16571A^2 + 0.498292B^2 -1.26921C^2 \]
3. \[ \text{MRR} = 28274.3 + 6361.75A + 9922.49B + 10629.4C + 4241.18AB + 2827.43AC + 53BC + 2800.95A^2 -4214.68B^2 -2800.92C^2 \]
4.2 Impact of Machining Boundaries on surface unpleasantness or roughness

The plot for the response surface roughness (Ra) of the machined specimen is illustrated in Figure 4 (a to c). These plots provide the effect of inputs on the response surface and also show the change of surface roughness with each parameter involved in the experiment. Figure 4 (a–c) illustrates the surface plots presenting the interaction effect of any two input parameters on the surface roughness where the other parameters are on their intermediate level. From the plot, it can be observed that the feed significantly affects Ra value. Figure 4(a) uncovers that when feeding rate increments from 0.15 mm/rev to 0.25 mm/rev, the surface roughness value additionally increments from 2.45 µm to 4.11 µm. This plot additionally shows that there is a slow augmentation in surface roughness or unpleasantness with increment in speed. Figure 4(b) shows the connection impact of feed rate and depth of cut on surface harshness. From the surface plot, it tends to be seen that both boundaries have a huge impact on surface inconsistency. The figure shows that high feed rate and high depth of cut during cutting activity causes more surface abnormality. The figure uncovers that with a change in feed rate from 0.15 mm/rev to 0.25 mm/rev, the surface unpleasantness value likewise changes from 2.47 µm to 4.16 µm. Additionally, figure 4(c) shows that with increment in speed and depth of cut, Ra value also increases.

![Figure 4(a). Surface plot of Ra versus feed rate and spindle speed](image1)

![Figure 4(b). Surface plot of Ra versus feed rate and depth of cut](image2)

![Figure 4(c). Surface plot of Ra versus spindle speed and depth of cut](image3)
4.3 Effect of parameters on Rz

The 3D plot for Rz esteem as appeared in figure 5(a-c). It uncovers that at lower feed rate and lower spindle speed in chosen range for this experimentation gives better surface finish and with increment in the depth of cut surface roughness values increments. Feed rate and depth of cut show more interaction effect when compared with spindle speed. Figure 5(a) shows that when feed rate has increments from 0.15 mm/rev to 0.25 mm/rev, Rz value additionally shows increments from 13.39 to 19.32 µm. It likewise shows that at high estimation of shaft speed, there is a low estimation of Rz value, 11.74 µm. Figure 5 (b) shows the interaction effect of feed rate and depth of cut on surface quality when shaft speed is kept at the transitional level. It uncovers that with increment in feed rate and depth of cut Rz esteem increments from 12.89 µm to 17.97 µm. Figure 5 (c) speaks that Rz value influences much with a depth of cut as compared with cutting speed when feed rate was kept steady.

Figure 5(a). Surface plot of Rz versus feed rate and spindle speed

Figure 5(b). Surface plot of Rz versus feed rate and depth of cut

Figure 5(c). Surface plot of Rz versus spindle speed and depth of cut

4.4 Impact of machining boundaries on Material removal rate

In figure 6 (a-c) response surface plots are given regard to chosen boundaries. In all plots, there are three parameters or boundaries (shaft speed, feed rate, and depth of cut) and one yield boundary (MRR). Each plot shows the connection between two input boundaries and one yield boundary while
keeping the third input boundary as steady. From figure 6(a) it tends to be seen that MRR increment with increment in feed and shaft speed when the depth of cut was kept steady. Figure 6(b) where speed was consistent it was seen that MRR increment with feed just as depth of cut. Further, it was seen that the depth of cut has more impact on MRR. Similarly, it increments from 10602.8 mm$^3$/min to 31808.6 mm$^3$/min. Figure 6(c) likewise shows a sharp addition in MRR with increment in the depth of cut when the feed was steady.

**Figure 6(a).** Surface plot of MRR versus feed rate and spindle speed

**Figure 6(b).** Surface plot of MRR versus feed rate and depth of cut

**Figure 6(c).** The surface plot of MRR versus spindle speed and depth of cut

### 4.5 Optimization of machining parameters for the desired response

Optimization of parameters involved in machining is the best method to achieve the desired quality. In this investigation, the main aim was to optimize the parameters for higher material removal rate and better surface finish in such a way the lower value of Ra and Rz can be achieved. In these multiple parameters are involved in optimizing multiple responses. To optimize multiple responses desirability method has been used in which desirability range between 0 to 1. From desirability test, the optimum cutting parameters 1800 rpm spindle speed, feed 0.15 mm/rev, 1.5 mm depth of cut will reflect the optimal results of Ra (2.424µm), Rz (12.946µm) and MRR(40997.8mm$^3$/min) as depicted in figure 7 with overall desirability 0.85 using Design Expert. The dot indicates the best solution found by the Design Expert solver within the given boundaries. The desirability of individual factor, output response and combined values are shown in figure 8.
Figure 7. Desirability function and optimal solution

Figure 8. Bar graph with maximum desirability of 0.85

5. Conclusions

CNC is widely used in many industries where accuracy is a critical factor during manufacturing like medical, defence, aerospace and any other industry, so investigation of machining parameters effect on output has to study regularly. The current investigation describes the effect of process parameters and optimization of parameters for output response, surface roughness and material removal rate on AA6061 alloy since it has wide application in car area, transport, aviation because of its high strength to weight proportion. Experiments were carried out by response surface methodology, Box-Behnken Design (BBD) using Design Expert 12. Significant ends have been derived from the experimentation in terms of wording for information and for clear representation 3D plots have additionally made.
1. Surface plots generated show the trends of output responses by varying any two parameters keeping the third parameter at an intermediate level.
2. On surface roughness values (Ra & Rz), it is discovered that the feed rate is having an incredible impact as compared to the depth of cut and spindle speed.
3. From the selected range of turning parameters depth of cut is a great contributor for material removal as compared to feed rate and spindle speed.
4. The predicted optimal results from desirability technique Ra, Rz, MRR are 2.424 µm, 12.946 µm, 40997.8 mm³/min. Respectively with a combined desirability value 0.85 out of 1.
5. The optimum input parameters for minimum surface roughness and greatest MRR are 1800 rpm, 0.15 mm/rev, 1.5 mm, spindle speed, feed rate and depth of cut respectively.
6. Any set of optimum input parameters can be identified by taking into consideration of surface roughness and material removal rate for AA6061 alloy.
7. The developed empirical model can be utilized to predict the response value in terms of feed rate, depth of cut and spindle speed at 95% confidence level.

6. Future scope
The work can be extended for optimizing power consumption, tool life, the effect of tool vibration, forces involved during machining, production cost and production time and other optimization technique like AAN(Artificial neural network), GA(Genetic algorithm) and comparison of results obtained by a different optimization technique.

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