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Application of Response Surface Approach to Optimize Surface Roughness in Aluminum Turning

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***Abstract*— The development of quality products is of significant importance in modern manufacturing industries. With its widespread usage in defence, aerospace, automotive and electronics, aluminum demands precise machining techniques for optimal performance. However, modelling and optimizing the machining process parameters are difficult tasks. The present study emphases on the machining of aluminum 7076 fuse body using response surface methodology (RSM). Cutting velocity, feed rate and depth of cut are machining parameters whereas; surface roughness is the response parameter. Modelling and optimization of process constraints for the best quality of work part is accomplished. The outcomes of this research contribute to meeting the evolving demands of precision manufacturing industries.**

***Keywords*— Surface roughness, optimization, response surface methodology.**

I. Introduction

The precision engineering industry, particularly CNC turning, acting a vital part in producing high-quality components for various applications. Aluminum, with its favorable properties such as lightweight, erosion resistance, and exceptional machinability, is widely used in aerospace automobile and marine engineering, as well as electronics industries [1,2,]. Enhancing the process parameters in machining of aluminum work part critical for increasing productivity, lowering production cost and improving product quality. Response surface methodology (RSM) is a mathematical technique widely used to enhance process variables in manufacturing process. RSM included experiment design, process modelling as well as optimization of parameters to attain the desired output. In the context of CNC turning of aluminum fuse bodies, RSM offers a systematic tactic to determine the finest combination of machining variables for achieving the desired surface finish, accurate dimension, and minimizing wear on tools.

Fuse body part is very crucial internal component in rockets, aircraft bombs, guided missiles, grenades and mines etc. Manufacturing of a fuse body is a big challenge to Industries because it is manufactured with better accuracy and precision. Total 30 operations are to be carried out on fuse body, 10 operations from CNC lathe machine and 20 operations from VMC machine out of that turning operation of fuse body using conventional coolant for enhancing the machining (VMC) efficiency and surface roughness. Researchers are sued various techniques for machining of aluminum work part as discussed in the subsequent paragraph.

Rudrapati et al. (2016) is investigated the influence of process parameters for enhancing surface quality of aluminum alloy using hybrid RSM-TLBO approach [1].

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Similarly, Nataraj and Balasubramanian optimized machining parameters including spindle speed, depth of cut, and feed rate, to achieve enhanced surface finish [2]. Saravanakumar et al. [3] determine the finest combination of input parameters for minimizing surface roughness, Additionally, their study demonstrated that genetic algorithms could effectively optimize material removal rates and surface roughness. Asiltürk and Neseli [4] recognized mathematical representations for surface finish. It is reviewed how surface roughness is affected by cutting parameters using the RSM. Santosh et al. [5] examined the betterment of statistical measure of regression model with ANN over RSM model. Asilturk et.al [6] The RSM and Taguchi methods are used to define the finest machining velocity, feed, tool depth and radius with the goal of achieving the lowest possible surface roughness. Sahoo et.al [7] created mathematical model for estimating surface roughness in CNC. RSM is successfully used to estimate the impact of surface roughness parameters. Sahoo et.al [8] developed multi output optimization technique is proposed, which combines WPCA and RSM. The experiments were represented in improved surface roughness and reduced tool vibration. Ranganath et.al [9] created response surface methodology and found that as speed increases, roughness increases; however, surface roughness significantly deteriorates as feed and depth of cut rise. Nataraj et.al [10] observed the temperature, roughness, and work tool interaction. It showed that increasing the speed results in best surface finish. Aggarwal et.al [11] and Sharma et.al [12] examined RSM and Taguchi method to determine the best machining parameter. 3D plots exposed that a cryogenic condition significantly reduces power consumption [11]. Gopal Mahesh [13] applied RSM and Taguchi techniques to aluminum 6061 work piece material with a coated carbide cutting tool and presented better surface finish. Kumar et.al [14] developed the Box Behnken method using RSM to achieve better surface texture and maximum material removal rate (MRR). Basha et.al [15] discovered that the best cutting condition were achieved with optimal process parameters, resulting in lowest possible value of surface roughness using a genetic algorithm. Butola et.al [16] developed response surface methodology to determine the ideal input parameter. The 3%, 6% and 9% reinforcement samples had surface roughness values of 1.47, 1.117, and 1.02 micrometers, respectively. Akhtar et.al [17] investigated the optimal process parameters for turning aluminum 7075 alloy. The L27 array Taguchi method increase material removal rate, had the lowest machined roughness and required the least amount of machining force. Kable et.al [18] proposed multi- optimization, which takes into account surface finish, MRR, machining force, cutting temperature and tool wear. The optimal parameter setting results in a better surface finish when using a coated tool. Deshpande et.al [19] used the advanced optimization techniques. The performance of all algorithm or optimization techniques is calculated using the most favorable outcomes. Researchers developed and tested models to find the best input factors for achieving definite surface quality by using surface response method. Researchers reported optimizing turning operations using various optimization approaches but no study found for aluminum fuse body machining parameter.

II. EXPERIMENTATION

A bar of aluminum 7076 with 25mm diameter and 28mm is selected for CNC turning operation as displayed in Fig.1, The composition of pure aluminum 7076 includes magnesium, silicon, manganese, and lithium, along with copper, zinc, small amount of zirconium lead, lead bismuth and nickel. Chromium, titanium and traces of iron are also inevitably present in minor quantities as shown in Table1. A PCLNL 2525 M12 turning tool is used for turning operation on CNC lathe machine. A castor and soya bean oil were chosen after reviewing the literature. As a result, for optimal lubrication and cooling, a 1:1 soya bean oil and castor oil is conceded to the machining zone utilizing the MQL system.

Fig.1 CNC machine

TABLE I. COMPOSITION OF ALUMINUM BAR 7076

Elements	% weight
Fe	0.08
Si	0.06
Cu	0.004
M	0.005
Ti	0.005
V	0.007
Zn	0.008
Mn	0.002
Na	0.004
AI	Remaining

III. DESIGN OF EXPERIMENT

Experiment design is a valuable instrument for obtaining and analyzing data under various kinds of conditions. The main focus of design of experiment is to compare different alternatives and discover significant parameters for an optimal response. In the Box-Behnken design (BBD), factors' lower values are input as -1, while their higher values are represented as +1, and their middle levels are represented as 0. Table 1 lists the choice of input constraints such as machining velocity (v), feed level (f) and depth of cut (d) based on examination of the works and a standard design methodology. Table 3 shows 15 experiment runs prepared with RSM by MINITAB 18 software.

BBD is a style of RSM used for designing experimentation to examine the response of a process or system to multiple factors. It is particularly useful when the factors' relationships with the response are anticipated to be approximately linear and there's no significant curvature in the response surface as represented in fig.2.

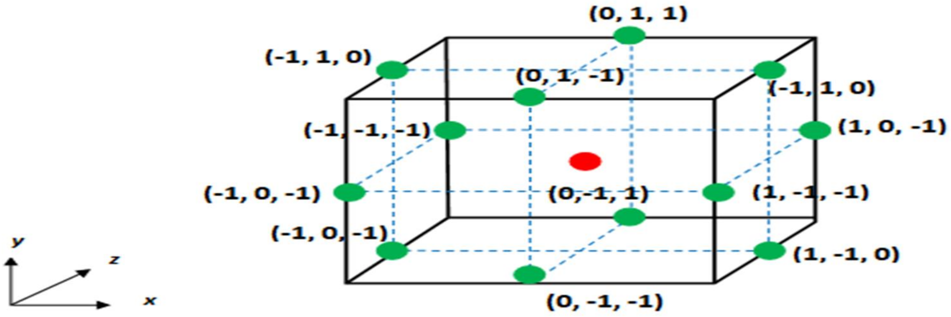

Fig.2 Box-Behnken Design

BBD is effective and sturdy investigational designs for discovering the response surface in a relatively small number of runs. They are widely used in several fields including engineering, chemistry, and manufacturing for process optimization and product enhancement. Table 2 shows the three level of CNC turning.

TABLE II: MACHINING PARAMETERS FOR CNC TURNING OF ALUMINUM BAR 7076SS

Parameters	Lower level	Medium level	Higher level
Machining velocity, v (m/min)	240	260	280
Feed level, f (mm/rev)	0.25	0.30	0.35
Depth level, d (mm)	1	1.5	2

TABLE III: EXPERIMENTAL VALUES OF TURNING ALUMINUM BAR 7076

Run Order	Machining velocity, v (m/min)	Feed level, f (mm/rev)	Depth of cut, d (mm)	Machining surface roughness (μm)
1	250	0.4	2	1.5
2	200	0.2	1.5	1.6
3	250	0.3	1.5	1.3
4	300	0.4	1.5	1.1
5	200	0.3	2	1.6

6	250	0.4	1	1.4
7	300	0.3	1	1
8	250	0.2	2	1.4
9	200	0.3	1	1.6
10	300	0.3	2	1
11	250	0.2	1	1.3
12	250	0.3	1.5	1.4
13	200	0.4	1.5	1.6
14	300	0.2	1.5	1.1
15	250	0.3	1.5	1.5

IV. RSM MODELLING

RSM is a gathering of numerical method to model and examine the connection between several independent variables (factors). RSM is normally employed in experimental design to enhance processes, improve product quality, and realize the interactions among variables. The response surface methodology is implemented in the MINITAB 18 software program to illustrate the input-output relationship. The empirical results reveal an association among the machining constraints (v, f, and d) and response constraints (Ra), as shown in Table 3.

Regression Equation

$Ra = 2.585 - 0.005500\, v + 0.250\, f + 0.0500\, d$

V. STATISTICAL ANALYSIS OF PARAMETERS FOR SURFACE ROUGHNESS

Machining surface roughness is the output parameter, as indicated in table 3, while machining velocity (v), feed level (f), and depth of cut (d) are treated as proces parameters in the parametric analysis for assessing the effects of CNC turning machine. Better surface finish attained at higher spindle speeds, according to the residual plot. The surface roughness rises as the feed level and depth of cut increase. The residual plot for Ra, which includes the residual compared to fits, residual versus normal probability plot, residual versus experimental values, and residuals histogram, is displayed in Fig. 4. As can be observed from Fig. 4a, the data is normally distributed since the residuals closely resemble a line in the systematic probability graph. It indicates that the measured and estimated values for Ra have a good relationship. The residuals and estimated values in Fig. 4b, residual versus fits, show the smallest deviation. The residual information is displayed in Fig. 4c's histogram. The values of residuals vs experimental data are displayed in Figure 4d, with the values ranging above and below the zero line. The entire analysis of the probability and residual graphs shows that the model that was produced for Ra is highly effective at making accurate predictions.

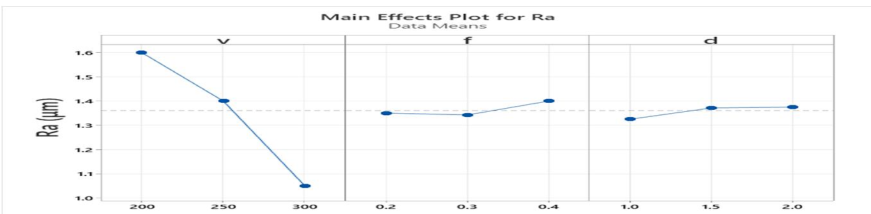

Fig. 3 Surface roughness in main effect plot

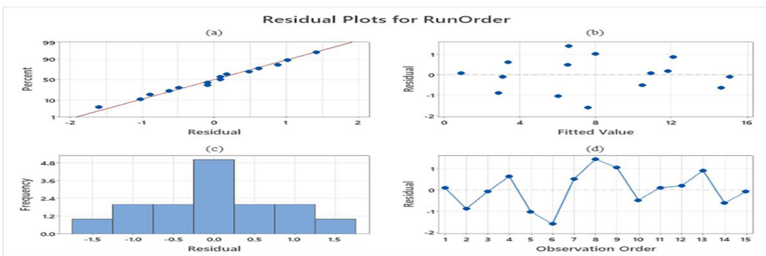

Fig. 4 Surface roughness in residual plot

VI. RESULT AND DISCUSSION

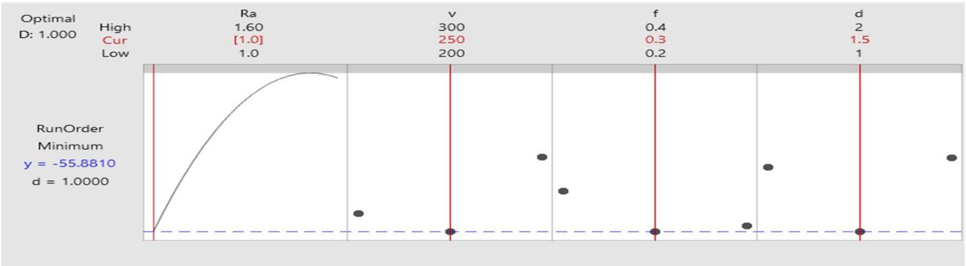

Fig. 5 Response optimization

In the framework of experiment design, RSM is typically measured. This is a numerical method for modelling and examining problems when a response of attention is subjective by a numeral of factors. figuring out a suitable valuation for the precise practical relationship between a group of self-governing factors, such as speed, feed, and depth of cut, and the response variable, surface irregularity. This work uses the RSM optimizer to estimate optimal cutting settings, including machining velocity (250 m/min), feed level (0.3 mm/rev) and depth of cut (1.5 mm). It is estimated that the corresponding machining roughness value is 1 µm. The arithmetic analysis of surface quality is produced using the generated data. Therefore, by having a comprehensive grasp of the key parameters, the anticipated values can be used to improve the response parameters. Using surface response methods, the statistical analysis demonstrates how input parameters affect replies.

VII. CONCLUSION

Utilising a CNC turning machine to machine aluminium bar 7076, the current study demonstrates how different process parameters affect the associated response parameter. The following conclusions are reached using the response surface methodology technique:

- Machining velocity, feed level and depth level are used as inputs whereas machining surface roughness is used as output to frame RSM model.
- The surface roughness residual plot indicates a reduction in surface roughness with rising speed.
- Additionally, the residual plot for surface finish specifies that roughness rises with feed level and depth of cut increases.

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