ORIGINAL RESEARCH PAPER

Engineering

INFLUENCE OF PROCESS PARAMETERS ON 6065 – T6 ALUMINUM ALLOY USING CNC END MILLING – A FUZZY APPROACH

KEY WORDS: CNC Vertical Milling Machine, 6065-T6 Aluminum Alloy, Fuzzy Logic, ANOVA, Surface Roughness And Material Removal Rate.

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ABSTRACT

The present work deals with the investigation of performance parameters of surface roughness and material removal rate of the machined parts during milling of Aluminum alloy 6065-T6 using CNC vertical milling machine with High speed steel milling, Carbide tool cutter by optimizing the process parameters such as speed, feed, cutting environment, depth of cut and cutting tool. The experiments are conducted based on Taguchi design of experiments with an orthogonal array (L16) the optimization of process parameters based on performance measures are done by using Fuzzy Logic. Also, the most influential process parameters are finding out by using ANOVA technique. Ideal execution parameters are found for smaller surface roughness and larger MRR utilizing the MINITAB and MATLAB software's.

INTRODUCTION

The important goal in the modern industries is to manufacture low cost, high-quality products in a short time. Milling is the most common method employed for metal removal and especially for the finishing of machined parts. It is widely employed in a variety of manufacturing units such as aerospace and automotive sectors. Surface Roughness is a generally used commodity consistency index and is important for mechanical parts. It is of considerable significance for the pieces to attain the desired surface level. Surface roughness is an indicator of a product's consistency and a consideration that significantly affects the cost of production. It can be generally stated that the lower the desired surface roughness the more the manufacturing cost and vice versa.

An end mill is a type of milling cutter used in industrial milling applications as a cutting tool. In its operation, geometry, and development, it is distinct from the drill bit. While a drill bit can only be cut in the axial direction, it can be cut in the radial direction by other milling bits. Not all mills will cut axially; they are known as end mills, those designed to cut axially. In milling applications, such as profile milling, tracer milling, face milling, and plunging, end mills are used. For the present research work, High Speed Steel (HSS) milling, Carbide tool cutter is used for machining operations and they are shown in Figure 1(a) and 1(b).

Figure 1(a): Carbide Tool Milling Cutter

Figure 1(b): Carbide Tool Milling Cutter

A large number of researchers conducted research on CNC Vertical Milling Machine with different types of alloys as well as end mill cutters and find out the performance parameters related to optimized process parameters. Some of the research findings are summarized below:

Dr. Mike S. Lou et al. [1] developed a multi-regression model that can forecast the surface roughness on the surface of the specimen (Al-6061) on which end milling operation has been carried out using a CNC machine. **Ghani, et al., [2]** A research on AISI H13 hardened steel is presented in order to optimize cutting parameters in end milling machines with TiN coated P10 carbide insert tool under high cutting speed semi-finishing and finishing conditions using Taguchi optimization methodology. **Julie Z. Zhang, et al., [3]** is presented a study on surface roughness optimization of CNC face milling operation using Taguchi Design methodology for machining on aluminum blocks. **Bharat Chandra Routara, et al., [4]** studied a multi-objective optimization problem by applying utility concept coupled with Taguchi method through UNS C34000 Medium Leaded Brass CNC End Milling. **Seref Ayku et al., [5]** developed an ANN model to foresee the surface roughness of Castamide material after machining process. **Surasit Rawangwong, et al., [6]** In semi-solid AA 7075 face milling, the effects of cutting parameters on surface roughness are studied. **Avinash A. Thakre [7]** presented a work on 1040 MS material on CNC vertical milling machine using carbide inserts to optimize the milling machining parameter to minimize surface roughness by using Taguchi method. **B. Vijaya Krishna Teja et al. [8]** An experimental research was performed on the performance properties of AISI 304 stainless steel during the CNC milling process. **J. S. Pang, et al., [9]** is introduced the application of Taguchi methodology for optimization of CNC end milling cutting parameters for machining on the hybrid composite material halloysite nanotube with aluminum reinforced epoxy matrix (HNT/AL/Ep) under dry condition. **Lohithaksha M Maiyara, et al., [10]** The end milling process optimization parameter for Inconel 718 super alloy with multi-response parameters based on the Taguchi orthogonal array is analysed with grey relational analysis.

Based on literature survey, it is observed that most of the researchers are focused on single milling tool cutters and some lacuna in comparing the various end milling cutters. The present work focused with following objectives:

- To conduct the End Milling operations on Aluminum alloy 6065-T6 (AISI4130) workpiece by varying the process parameters using CNC Milling machine.
- To measure the roughness of the machine surface by using Talysurf instrument.
- To optimize the performance parameters for improving the machining characteristics such as Surface Roughness (R_a) and Material Removal Rate (MRR) based on Fuzzy Logic.
- To find out significance of each process parameter on output responses by using ANOVA.

METHODOLOGY

Taguchi's strategy is an effective method for the plan of a brilliant framework. It gives a productive as well as an orderly way to deal with improves plans for execution and quality. Moreover, Taguchi parameter configuration can lessen the change of framework execution. The experiment is governed by the following steps are:

- Select the appropriate orthogonal array and assign these parameters to the orthogonal array.
- Conduct experiments on the basis of the orthogonal array structure.
- Analyze the experimental results using Fuzzy Logic and ANOVA.

A. Experimental Design

- **Process Parameter Selection:** Process parameters and their ranges are determined by the research work. The parameters are identified for the experiments such as Speed, Feed, Cutting Environment, Depth of Cut and Cutting tool.
- **Orthogonal array selection:** To select an appropriate orthogonal array for the experiments, on the basis of parameter selection and its levels. Here we have 5 parameters; 4 parameters are in four levels and 1 parameter in two levels are selected.
- **Conduct the experiment and Recording of responses:** Due to the mixed levels of parameters total sixteen experimental runs are conducted as per the Taguchi's L16 orthogonal array. The test runs are carried out at random to avoid a systematic error creeping into the experimental procedure.
- **Analysis using Fuzzy Logic and ANOVA:** The analysis of the performance parameters can be obtained by using Fuzzy logic and analysis of variance and find the most critical factors for getting the optimum performance parameters.

EXPERIMENTATION

A. Experimental Setup

An indigenous experimental setup of CNC Vertical Milling Machine (CNC-JV-55) has been carry out for machining of 6065-T6 Aluminum Alloy and it is shown in Figure 2. It consists of three special features compared to other milling machines, as explained below:

- **Totally Protected Slide Ways:** The slide ways and ball screws remain completely protected, preventing entry of chips and coolant. This adds the ease of maintenance and retention of built in accuracies over a long period of continuous use.
- **Twin Arm Automatic Tool Changer:** It is a simple and reliable cam operated mechanism Twin Arm Automatic Tool Changer (ATC) changes the tools accurately and swiftly. The ATC employs a Technical Random Memory system through shortest path.
- **High precision feed mechanism:** Slide traverses are reliable, fast and accurate. The JV series machines employs high precision linear motion guide ways and large diameter, pre-tensioned ball screws for the axis traverses. The locating, fixing surfaces for the linear motion guide ways are precision machined to close tolerances in all axes of perfect seating. Widely spaced guide ways allow optimal distribution of cutting forces

Figure 2: Experimental Setup of CNC Vertical Milling Centre

B. Experimentation

In this experimental work, Surface Roughness (SR) and Material Removal Rate (MRR) been considered for analyzing the machining performance. All these execution qualities are associated with machining parameters like Speed, Feed, Cutting Environment, Depth of Cut and Cutting tool. Investigations are performed by varying the control parameters randomly. Table 1 & 2 shows Machining conditions and process parameters and their levels utilized for experimentation.

Table – 1 machining Conditions

Workpiece	Aluminum Alloy 6065
Machine tool	CNC Vertical Milling Machine.
Tool material	Solid Carbide and HSS Tools
Other equipment used	MITUTOYO (SJ210)

Table – 2 Process Parameters And Their Levels

Parameter	Level 1	Level 2	Level 3	Level 4
Speed (rpm)	1000	1500	2000	2500
Feed (mm/min)	150	200	250	300
Cutting Environment	Fork Oil	Engine Oil	Soluble Oil	Coconut Oil
Depth of Cut (mm)	0.2	0.4	0.6	0.8
Cutting Tool	Carbide Tool	HSS Tool	---	---

Table 3 indicates the chemical composition of the workpiece material.

Table – 3 Chemical Composition Of 6065-t6 Aluminum Alloy

Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr
0.8 –1.2	0.4 –0.8	Max. 0.7	0.15 –0.40	Max. 0.25	Max. 0.15	Max. 0.15	0.04 –0.35

The responses for the above machining conditions with L16 orthogonal array are shown in Table 4.

Table – 4 L16 Orthogonal Array With Response Data

S. No.	Speed (rpm)	Feed (mm/min)	Cutting Environment	Depth of Cut (mm)	Cutting Tool	Machining Time (min)	MRR	Ra (mm)
1	1000	150	Fork Oil	0.2	Carbide	03:08	360	0.706
2	1000	200	Engine Oil	0.4	Carbide	02:18	960	0.705
3	1000	250	Soluble Oil	0.6	HSS	01:54	1800	1.059
4	1000	300	Coconut Oil	0.8	HSS	01:33	2880	1.807
5	1500	150	Engine Oil	0.6	HSS	02:58	1080	0.800
6	1500	200	Fork Oil	0.8	HSS	02:11	1920	1.084
7	1500	250	Coconut Oil	0.2	Carbide	01:48	600	0.710
8	1500	300	Soluble Oil	0.4	Carbide	01:28	1440	0.649
9	2000	150	Coconut Oil	0.8	Carbide	02:49	1440	0.536
10	2000	200	Coconut Oil	0.6	Carbide	02:04	1440	0.664
11	2000	250	Fork Oil	0.4	HSS	01:42	1200	0.908
12	2000	300	Engine Oil	0.2	HSS	01:23	720	0.958
13	2500	150	Coconut Oil	0.4	HSS	03:04	720	0.574
14	2500	200	Soluble Oil	0.2	HSS	01:40	480	0.977
15	2500	250	Engine Oil	0.8	Carbide	01:52	2400	0.797
16	2500	300	Fork Oil	0.6	Carbide	01:08	2160	0.477

OPTIMIZATION

Efficient optimization leads to the improved process control, which results in one or more of the following benefits: i). Lower product variation, ii). Higher value products iii). Increase throughput, iv). Reduce utility usage, and v). Improve safety. Because these benefits are economically significant, the use of advanced process control is essential to companies engaged in competitive markets.

A. Fuzzy Logic

A fuzzy logic model is built in the present work, based on the Mamdani process to determine the surface roughness and MRR of 6065-T6 aluminium alloy components as output parameters based on input parameters. Table 4 displays the fuzzy linguistic variables and functions for input and output parameters. To build and simulate the fuzzy model, MATLAB 10.0 programme is used.

The diagram of the defined Fuzzy model is shown in Figure 3. Fuzzification module, inference mechanism, defuzzification module and outputs are used in the fuzzy logic model.

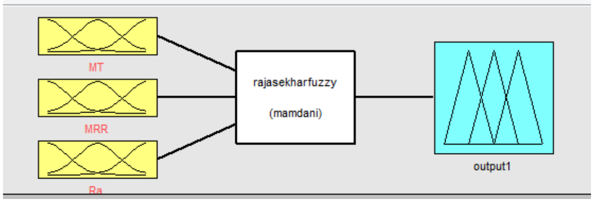

Figure 3: Layout – Fuzzy Model

Membership Functions:

The preference of membership functions (MF) for fuzzification relied on the appropriate event. The outline of the MF is a picture of mystery in the fuzzy vector. Experiments are carried out on 4 levels of process parameters dependent on DOE to achieve successful machining. In order to refine them and fix the dynamic relationships of input parameters, the Gaussian membership attribute is used to define the fuzzy sets for input variables. The triangular membership function normally has characteristics of a different value that steadily increase and decrease. Therefore through triangular membership functions, the output variables are inferred. Fuzzy membership functionality for the inputs. By post-tuning the fuzzy model viewer for better prediction accuracy using MATLAB tools, the parameters for the Gaussian and triangular membership functions are updated.

Fuzzy Rule:

In each computational loop, a fuzzy inference engine performs inference operations on enabled fuzzy rules to constitute an aggregate output. Fuzzy rules are generated from fuzzy feedback that can be collected from experts, tests, and previous process data. The rules for a Mamdani style fuzzy inference method with 5 inputs and 2 outputs were developed using experimental evidence. Based on the input method parameters for predicting surface roughness and MRR as the output, a rule base is formulated with a set of 16 rules.

B. ANOVA

Analysis of Variance (ANOVA) is a mathematical tool for evaluating the presence of variations between multiple means of population. Although the purpose of ANOVA is to distinguish variations between means of multiple populations, the procedure involves the study of various types of variation correlated with random samples. The researchers tried to decide whether all the therapies under review were similarly successful or whether any treatments were better than others.

RESULTS AND DISCUSSION

A. Fuzzy Logic

The output responses which are obtained in the Table 4 are optimized by using fuzzy approach and the corresponding results are tabulated in Table 5.

Table – 5 Fuzzy Grade For Normalized Process Parameters'

S. No.	MRR	Time (min)	Ra	Normalized Values			Fuzzy Grade
				MRR	M/c Time	Ra (mm)	
1	360	3.08	0.706	0	0	0.709	0.2391
2	960	2.18	0.705	0.2381	0.4167	0.7096	0.4537
3	1800	1.54	1.059	0.5714	0.713	0.4816	0.5982
4	2880	1.33	1.807	1	0.8102	0	0.5996
5	1080	2.58	0.8	0.2857	0.2315	0.6484	0.3954
6	1920	2.11	1.084	0.619	0.4491	0.4656	0.5016
7	600	1.48	0.71	0.0952	0.7407	0.7064	0.5313
8	1440	1.28	0.649	0.4286	0.8333	0.7457	0.6496
9	1440	2.49	0.536	0.4286	0.2731	0.8184	0.4854
10	1440	2.04	0.664	0.4286	0.4815	0.736	0.5351
11	1200	1.42	0.908	0.3333	0.7685	0.5789	0.5572
12	720	1.23	0.958	0.1429	0.8565	0.5467	0.5238
13	720	3.04	0.574	0.1429	0.0185	0.7939	0.3277
14	480	1.4	0.977	0.0476	0.7778	0.5344	0.4691
15	2400	1.52	0.797	0.8095	0.7222	0.6504	0.6837
16	**2160**	**1.08**	**0.477**	**0.7143**	**0.9259**	**0.8564**	**0.7525**

The response table maximum fuzzy grade is shown in Table 6 and Figure 4 are obtained for optimal process parameters by using MINITAB R17 software and it can be observed that the optimum input parameters are speed at 2500 rpm, feed at 300 mm, cooling environment – soluble oil, depth of cut at 0.6 mm and carbide tool.

Table – 6 Response Table For Means – Fuzzy Grade

Level	Speed	Feed	CE	DOC	CT
1	0.4805	0.3448	0.5083	0.4404	0.6079
2	0.5041	0.5025	0.4738	0.4799	0.4189
3	0.4881	0.5626	0.5466	0.5874	
4	0.5810	0.6438	0.5249	0.5460	
Delta	0.1005	0.2990	0.0728	0.1470	0.1890
Rank	4	1	5	3	2

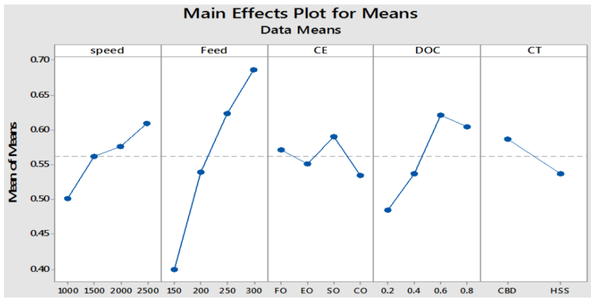

Figure 4: Main Effects Plot for Means of Fuzzy Grade

B. ANOVA

The most influential parameter for fuzzy grade is obtained by Using ANOVA and the responses are shown in Table 7.

Table – 7 Analysis Of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%
Speed	3	0.014919	0.014919	0.004973	4.37	0.192	5.93
Feed	3	0.174295	0.174295	0.058098	51.03	0.019	69.23
Cutting Envi.	3	0.005939	0.005939	0.001980	1.74	0.385	2.36
DOC	3	0.046337	0.046337	0.015446	13.57	0.069	18.40
Cutting Tool	1	0.008001	0.008001	0.008001	7.03	0.118	3.18
Error	2	0.002277	0.002277	0.001139			
Total	15	0.251769					

From the Table 7, the % contribution of values for speed 5.93%, feed 69.23%, cutting environment 2.36%, depth of cut 18.40% and cutting tool 3.18%. The feed and depth of cut are observed to be the most influential parameters. As this analysis is a parameter-based optimization design, it is clear from the above values that depth of cutting and feed is a key factor in ensuring efficient surface finishing and material removal speeds.

C. Confirmation Test Results

The conformation experiments are used to predict and verify the improvement in the quality characteristics for machining on 6065-T6 Aluminum Alloy. Table 8 shows the confirmation test results for surface roughness and MRR at optimal fuzzy parameters.

Table – 8 Responses At Optimal Parameters From Fuzzy Approach (experimental And Predicted)

Level	2500 rpm, 300 mm, Soluble Oil, 0.6 mm and Carbide Tool	
Responses	Experimental	Confirmation Test Result
Machining Time (min)	1.08	0.92
Surface Roughness (mm)	0.477	0.254
MRR	2160	2160
Fuzzy Grade	0.7525	0.8499

From Table 8, it can be observed that there is a moderate improvement between experimental and confirmation test of output responses.

CONCLUSIONS

The following conclusions are drawn based on the research work:

- Reviewed the effect of process parameters on CNC Vertical Milling Machine output measurements using an end mill cutter.
- The optimum process parameters at maximum fuzzy grade are obtained at: speed – 2500 rpm, feed – 300 mm, cooling environment – soluble oil, depth of cut – 0.6 mm and carbide tool
- Based on ANOVA, the most influential parameter for feed and depth of cut for fuzzy grade.
- From the confirmation test it is observed that there is a moderate improvement between experimental and confirmation test of output responses.

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