An Investigation of Optimum Cutting Conditions in Face Milling Semi-Solid AA 7075 Using Carbide Tool

Surasit Rawangwong, Jaknarin Chatthong, Romadorn Burapa, and Worapong Boonchouytan

***Abstract*—The purpose of this research was to investigate the effect of the main factors on the surface roughness in semi-solid AA 7075 face milling. The results of the research could be applied in the manufacture of automotive components and mold industry. The study was conducted by using computer numerical controlled (CNC) milling machine with 63 millimeter diameters fine type carbide tool with twin cutting edge. The controlled factors were the speed, feed rate and depth of cut which the bite cutter was not over 1 mm. For this experiment we used factorial designs and the result showed that the factors effected the surface roughness were the feed rate ratio and the speed while the depth of cut did not affect the surface roughness. Furthermore, the result of the test showed that the surface roughness was likely to reduce when using the speed 3,800 rpm and the feed rates was 1,000 mm/min. The result of the research led to the linear equation measurement value which was Ra = 0.156 - 0.000024 Speed + 0.000047 Feed rate. The equation formula should be used with the speed in the range of 2,600-3,800 rpm, feed rate in the range of 1,000-1,500 mm/min and the depth of cut of not over 1 mm. When the equation was used to confirm the research results, it was found that the mean absolute percentage error (MAPE) of the surface roughness obtained from the predictive comparing to the value of the experiment was 3.62 percent, which was less than the specified error it was acceptable.**

***Index Terms*—CNC milling machine, semi-solid AA7075, face milling, surface roughness, carbide tool.**

I. INTRODUCTION

Aluminum alloys are extensively used as a main engineering material in various industries such as automotive industries, the mould and die components manufacture and the industry in which weight is the most important factor. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. These materials help machining and possess superior

machinability index. Milling is one of the most commonly used machining processes in aluminum alloys shaping. It has considerable economical importance because it is usually among the finishing steps in the fabrication of industrial mechanical parts. Their effect on products is important because they may cause some critical problems such as the deterioration of surface quality, thus reducing the product durability and precision.

Manuscript received September 4, 2012; revised October 31, 2012.

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As mentioned above, surface roughness is an important measure of product quality. Surface roughness have an impact on the mechanical properties like fatigue behavior, corrosion resistance etc. Sometimes, various catastrophic failures causing high costs have been attributed to the surface finish of the components in question. As a result, there have been many great research developments in modeling surface roughness and optimization of the controlling parameters to obtain a surface finish of desired level since the only proper selection of cutting parameters can produce a better surface finish. Nevertheless, such studies are far from completion since it is very difficult to consider all the parameters that control the surface roughness of a particular manufacturing process. The parameters that affect surface roughness include machining parameters and cutting tool properties etc. In the manufacturing industries, various machining processes are adopted to remove the material from a workpiece for the better product. Similarly, end milling process is one of the most vital and common metal cutting operations used for machining parts because of its ability to remove materials faster with a reasonably good surface quality. In recent times, numerical controlled machine tools have been implemented to realize full automation in milling since they provide greater improvements in productivity, increase the quality of the machined parts and require less operator input.

A brief review of literature on roughness modeling in milling is presented here. [1] Developed the mathematical model of surface roughness for the end milling of 190 BHN steel considering only the center line average roughness parameter in terms of cutting speed, feed rate and depth of cut using response surface method. After that, [2], [3] Studied the effect of spindle speed, feed rate and depth of cut on roughness in end milling of Aluminum workpiece. They used in-process surface roughness recognition and a neural fuzzy system to predict the roughness. Later, [4] Considered neuro-fuzzy approach for roughness modeling in CNC down milling of Alumic-79. While, [5] Considered Taguchi method for optimization of surface roughness in end milling of hardened steel in terms of cutting parameters. Later, [6] Used genetic programming for surface roughness prediction in CNC end milling of 6061 Al in terms of machining parameters as well as vibrations. In the same year, [7] Investigated surface roughness in slot end milling of aluminum. Later, [8], [9] Analyzed the optimum cutting condition leading to a minimum surface roughness in end milling by combining the response surface method with neural network and genetic algorithm for aluminum and plastic mold parts. Later, [10] Investigated the influence of micro-end-milling cutting conditions on surface roughness of

DOI: 10.7763/IJIMT.2012.V3.321

a brass surface using response surface method. Later, [11] Developed a mathematical model for surface roughness considering the cutting parameters and tool geometry during end milling of medium carbon steel using response surface method. After that, [12] Have modeled surface roughness in high speed flat end milling of steel including total tool operating time along with other machining variables such as spindle speed, feed rate, depth of cut and step over. Later, [13] Incorporated the effect of cutting edge angle on roughness and texture generation on end milled steel surfaces. They have used response surface method deviation, skewness and kurtosis for evaluating the generated surface texture characteristics. Recently, [14] Used the Taguchi optimization method for low surface roughness value in terms of cutting parameters in the CNC face milling of Cobalt based alloy. More recently, [15] Have presented the optimization of cutting parameters for side milling of medium carbon steel with multiple roughness characteristics, viz., feeding direction roughness, axial direction roughness and waviness, using grey relational Taguchi approach.

Cutting aluminum alloys is a major manufacturing process in the automotive industries and the manufacturing of mould and die components. Milling with an end mill is one of the important machining processes for making profiles, slots, engraving, surface contouring, and pockets in precision molds and dies. The machining process is used in both roughing and finishing operations. Thus, the forming process; planning machining, milling, or milling the surface of the piece may cause loss of material. Such problems may be caused by several factors such as material, cutting speed, feed rate, cutting depth, and also the workers who have no expertise. The researcher therefore, was interested in investigating any proper condition in semi-solid AA 7075 milling processes to benefit automotive industries and the manufacturing of mould and die components industries and to reduce time and cost for the better quality product.

II. Equipment and Tools

This research study aimed to investigate the effect of main factors on the surface roughness in semi-solid AA 7075 face milling process by computer numerical controlled (CNC) milling machine and using carbide tools of 63 millimeter diameter with twin edges type. The following equipment and instrument were used.

1) Computer numerical controlled milling machine of model DMG type DMC 835N with technical specifications including a maximum speed of 18,000 rpm and maximum feed rate of 20,000 mm/min.
2) Workpiece samples: Semi-solid AA 7075. The size of the workpiece was 50×50 mm cross section and 100 mm in length.
3) Cutting tools: Carbide tool model Kennametal type KEGT25L512PEERLDJ. Fine type carbide tool.
4) Face milling chuck: Fine type carbide tool with 63 millimeter diameter edge with twin cutter type of the maximum speed of 18,000 rpm.
5) A surface roughness measuring device of model Mitutoyo Surf Test 301.

III. Methodology

There were four main procedures that serve the purposes of conducting this study. The first procedure was investigating the sample size to design the face milling. The second was studying the expected factors in making an effect on surface roughness in the semi-solid AA 7075 milling process. Third, it was a pilot treatment to examine the optimum surface roughness and lastly was to take the real treatment in order to confirm the results. These were detailed as follows:

Procedures no. 1, investigated the sample size to design the semi-solid AA 7075 milling machine by using program Minitab R.15 with statistic reliability and significance at 95% and 5% respectively.

Procedures no. 2, studied the factors affecting surface roughness in the semi-solid AA 7075 face milling process by using completely randomized factorial designs with 5 repeated treatments for reducing the variation of sampling. Program Minitab R.15 was employed to calculate statistic values and to analyze the 2^3 factorial designs. The three factors and the responsive surface roughness value were shown in Table I.

TABLE I: The Allocated Variation in Procedure No.2

Factor	High	Low
Speed (rpm)	3,500	2,500
Feed rate (mm/min)	1,400	1,000
Depth of cut (mm)	1	0.5

Procedures no. 3, as general factorial design was used for identifying the optimum surface roughness (R_a) with the allocated speed of 3 levels: 2,600 3,000 and 3,800 rpm, the allocated feed rate was classified into 3 levels; 1,000 1,300 and 1,500 mm/min. Furthermore, the depth of cut was stable at 0.5 mm which did not affect the surface roughness from the first treatment. The findings were shown in Table II.

TABLE II: The Allocated Variation in Procedure No.3

Factor	Level 1	Level 2	Level 3
Speed (rpm)	3,800	3,200	2,600
Feed rate (mm/min)	1,500	1,300	1,000
Depth of cut (mm)	0.5	0.5	0.5

Procedure no. 4, took the real treatment in order to confirm the results. This treatment was tried out to confirm the conformation of each treatment by using a linear equation of procedure no.3 to predict the surface roughness. The prediction was done by randomly selecting 12 cutting conditions and replicating each condition 4 times. The margin of error was not over 5%.

IV. Results

The experiment for finding the sampling sizes used statistical values in data analysis. The reliability was at the 95% or significance at 5%. The feed rate was at 1,100 mm/min; the speed was 2,700 rpm; the depth of cut was at 1 mm. The twelve repeated treatments revealed that the mean average of surface roughness was at 0.16 μm and the standard deviation was 0.011 μm. Furthermore, the result of the sample size investigation was a 5-sampled size.

According to the procedure no.2, the analysis of the variance of surface roughness R^2 was of 86.66% and the Adjust R^2 was of 83.75%. This meant that the data variance value was at 100 μm^2. The variance value of 86.66 μm^2 could be explained with regression model but the remaining value was not explainable due to the uncontrollable variables.

The details are as follows: it is obviously seen that the most variance of surface roughness (R_a) is implied as a regression model. This can be said that the design of each treatment is appropriate and accurate, as shown in Table III.

Table III and Fig. 2 revealed that the main factors affecting the surface roughness of semi-solid AA 7075 were feed rate and speed with tendency of higher surface roughness when feed rate and speed increase from 1,000 to 1,400 mm/min and 2,500 to 3,500 rpm respectively. The surface roughness reduced when the feed rate decreases and the decreased speed decreases the surface roughness of semi-solid AA 7075 as shown in Fig. 1 and Fig. 2, showed that no other factors affect the surface roughness.

TABLE III: ANALYSIS OF VARIANCE RESULTS OF SURFACE ROUGHNESS VALUES

Analysis of Variance for Ra, using Adjusted SS for Tests						
Source	D.F.	Seq SS	Adj SS	Adj MS	F	P
Speed	1	0.0110556	0.0110556	0.0110556	112.10	0.000
Feed rate	1	0.0091506	0.0091506	0.0091506	92.78	0.000
Depth of cut	1	0.0001056	0.0001056	0.0001056	1.07	0.308
Speed*Feed rate	1	0.0000156	0.0000156	0.0000156	0.16	0.693
Speed*Depth of cut	1	0.0000506	0.0000506	0.0000506	0.51	0.479
Feed rate*Depth of cut	1	0.0001260	0.0001260	0.0001260	1.28	0.267
Speed*Feed rate*Depth of cut	1	0.0000042	0.0000042	0.0000042	0.04	0.837
Error	32	0.0031560	0.0031560	0.0000986		
Total	39	0.0236644				
S = 0.00993101 R-Sq = 86.66% R-Sq(adj) = 83.75%						

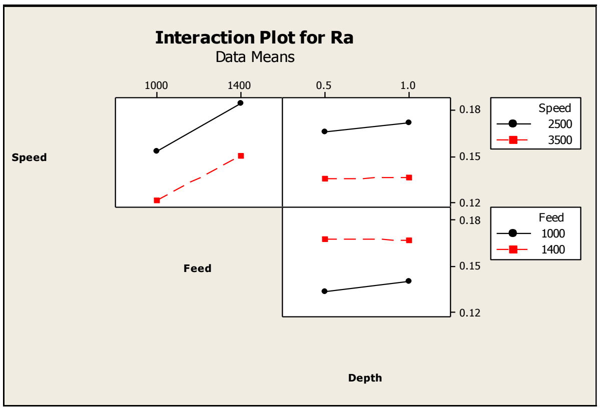

Fig. 1. The interaction effects plot of surface roughness

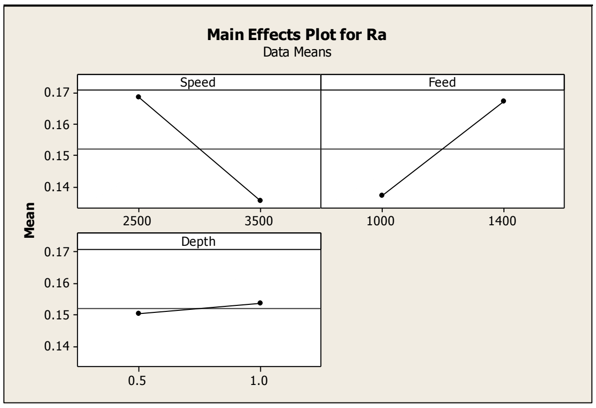

Fig. 2. The main effects plot of surface roughness

Based on procedure no. 3 and data analysis which was conducted to identify the variation of surface roughness of semi-solid AA 7075 and adjust for variance analysis, the findings revealed that the decision making coefficient of designing surface roughness measurement was at 86.96% and the adjust R^2 was at 85.31%. This meant that if the variance value was at 100 μm^2, the 86.96 μm^2 of variance could be implied by the regression model. Anyway, the rest of data could not be interpreted because of the uncontrolled variable.

Therefore, the data variance in measuring the surface roughness could be implied from the feed rate and speed. These brought about the accurate designing treatment and were appropriate for data analysis. The analysis of variance in surface roughness (R_a) is shown in Table IV.

The basic treatment shown in Table IV, Fig. 3 and Fig. 4 presents that the main factors influencing the surface roughness of semi-solid AA 7075 were feed rate and speed. The surface roughness reduces when the feed rate decreases and the decreased speed reduced the surface roughness of semi-solid AA 7075 as shown in Fig. 4 and Table V. The other factors did not effected the surface roughness.

The regression analysis of the surface roughness of semi-solid AA 7075 was the regression analysis of feed rate and speed. The analysis was carried out by using the data from the variables adjustment experiment. The ratio of feed rate was classified into 3 levels: 1,000 1,300 and 1,500 mm/min; the speed was set into 3 levels: 2,600 3,200 and 3,800 rpm. Further, the depth of measurement was stable at 0.5 mm. The recessive test is program Minitab R.15. The findings are shown in Table V.

The analysis of regression model can be related to the main factors and the surface roughness (R_a) as shown in this linear equation:

$$R_a = 0.156 - 0.000024 \ Speed + 0.000047 \ Feed \ rate \quad (1)$$

The result of procedure no.4 is confirmed all treatments by using an algebraic equation to predict the surface roughness of semi-solid AA 7075. The sampling of cutting process within the limited area can be compared to the real means. The error was less than 5% and the mean absolute percent error (MAPE) as shown in Eq. 2. was just 3.62%. This is acceptable. And comparison of the surface roughness as shown in Fig. 5.

TABLE IV: ANALYSIS RESULTS OF SURFACE ROUGHNESS VALUES

Analysis of Variance for R_a, using Adjusted SS for Tests						
Source	D.F.	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.0097197	0.0097197	0.0048598	121.83	0.000
Feed rate	2	0.0069360	0.0069360	0.0034680	86.94	0.000
Speed*Feed rate	4	0.0001072	0.0001072	0.0000268	0.67	0.614
Error	63	0.0025130	0.0025130	0.0000399		
Total	71	0.0192759				
S = 0.00822474 R-Sq = 86.96% R-Sq (adj) = 85.31%						

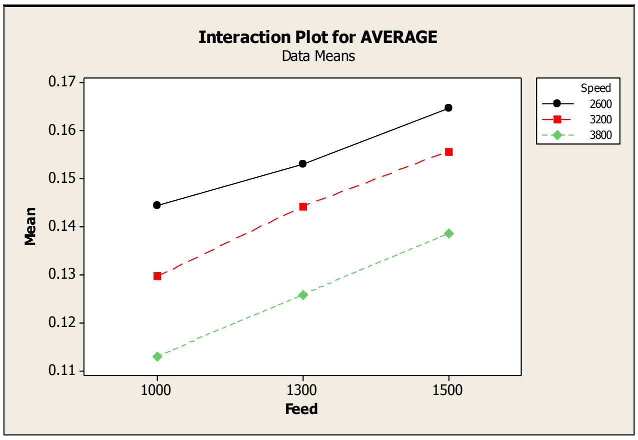

Fig. 3. The interaction effects plot of surface roughness

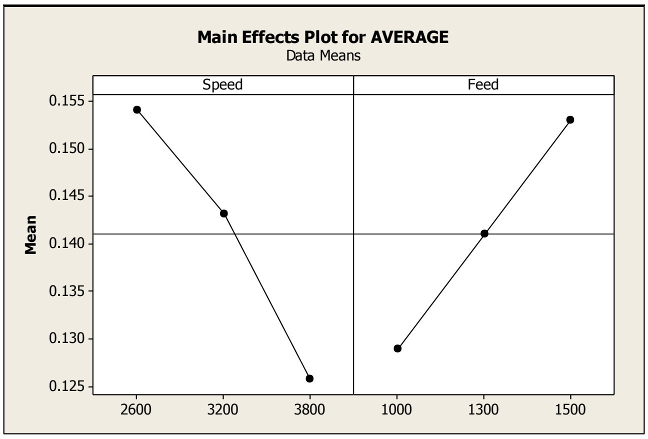

Fig. 4. The main effects plot of surface roughness

TABLE V: REGRESSION ANALYSIS: SURFACE ROUGHNESS VALUES, SPEED AND FEED RATE

Regression Analysis: R_a versus Speed, Feed rate				
The regression equation is Ra=0.156-0.000024Speed+0.000047Feed rate				
Predictor	Coef	SE Coef	T	P
Constant	0.156139	0.006882	22.69	0.000
Speed	-0.00002351	0.00000155	-15.12	0.000
Feed rate	0.00004746	0.00000371	12.80	0.000
S = 0.00646180 R-Sq = 85.1% R-Sq (adj) = 84.6%				

$$MAPE = \frac{1}{n}\left(\sum_{t=j}^{T}\frac{|e_t|}{d_t}?\ 00\right) \qquad (2)$$

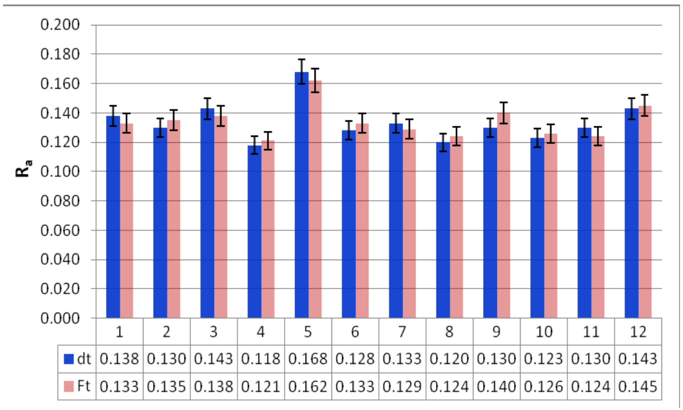

Fig. 5. Comparison of the surface roughness

V. CONCLUSION

The purpose of the study of investigating the surface roughness in semi-solid AA 7075 face milling process by CNC milling machine and using face mill cutting tool with twin edges type was to identify the means of the surface roughness of semi-solid AA 7075 face milling process, which was a part plastic mold and part automotive production. The completely randomized block factorial design was applied to the research. The main factors including speed, feed rate and depth of cut were investigated for the optimum surface roughness. It could be concluded as following;

1) Cutting speed significantly effects the surface roughness of semi-solid AA 7075 followed by feed rate. The result also indicates that lower value of speed and lower feed tended to decrease the surface roughness.
2) The linear equation in this research was as follows.

$$R_a = 0.156 - 0.000024\ Speed + 0.000047\ Feed\ rate$$

This equation could be applied with face mill cutting tool with 2 edges speed mill cutting tool was at 2,600-3,800 rpm and the feed rate at 1,000-1,500 mm/min.
3) When comparing the confirmation treatment and the results by using the referred formulation, the measurement was 5 % of errors. The mean absolute percentage error (MAPE) was of 3.62%, which has fewer than the margin of error that could be acceptable.

ACKNOWLEDGMENT

The authors would like to thank the Rajamangala University of Technology Srivijaya, (RMUTSV) Songkhla, Thailand for financial support and thank the staff of automatic machine laboratory, RMUTSV.

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