

A Comparison of Milling Cutting Path Strategies for Thin-Walled Aluminium Alloys Fabrication

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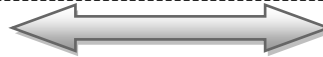
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Abstract

This project presents a comparison of milling cutting path strategies for thin-walled aluminum alloys fabrication. To search for more efficient cutting path strategies for thin-walled parts, an interactive process planning and analyzing method is introduced. Several rigid combinations of machining parameters are examined based on the evaluation of surface finish, thickness accuracy and machining time in the visual charts. In order to obtain the best cutting path strategy, MasterCam X MR2 software have been used to utilize the cutting path for machining thin-walled aluminum alloy parts into CNC end milling machine. The resulting of cutting path strategies is solved by experimental method. From the experiment, it was found that true spiral is the best machining strategy in term of thickness accuracy but lack of surface roughness when compared to other machining strategies. Not only the best surface roughness was observed for parallel spiral strategy but also the machining time was significantly better.

Keywords - CNC milling machine, MasterCam, thin-walled aluminum alloy.

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I. INTRODUCTION

These days, monolithic components are commonly used as structural parts in the aeronautical industry due to their homogeneity and excellent strength to weight ratio. Ribs, stringers, spars and bulkheads can be mentioned as an example. Monolithic parts are made of thin walls and webs, which confer enough stiffness to the whole part. Although they were usually made assembling several smaller parts, nowadays they are milled starting from a raw block of material and removing up to 95% of the weight of the initial block [1]. Hence, a high productivity can only be achieved increasing the removal rate as much as possible. The drawback is that, at high removal rate conditions, the lack of stiffness of the thin walls and webs makes static and dynamic problems appear, particularly, the self-excited vibration called chatter, which is the most complex and difficult to avoid by manufacturers. The application areas of thin-walled are in die and mould manufacturing. While, machining of thin-walled products that are mostly in aircraft and aerospace industry. Thin-walled products are often large and integral products for which typically up to 95% of the blank is machined or even more. As a consequence, unacceptable surface roughness levels, part damage and a lack of dimensional accuracy can be suffered [1]. With the higher demands on the speed and performance of the modern aircraft, the thin-walled aluminum alloy parts have been used broadly in aeronautics.

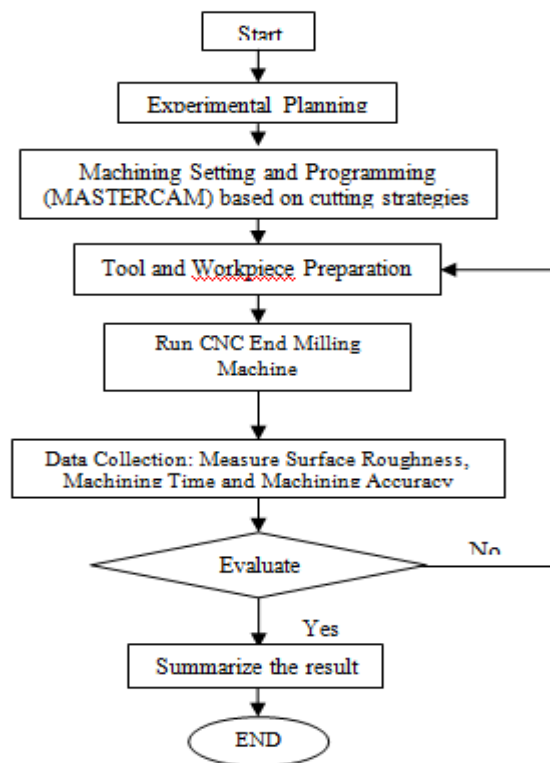
Due to the large area and low rigidity, the thin-walled plates are always machined in numerical control (NC) end milling process. However, owing to various reasons in the machining process, the thin-walled plates are very easy to deform under the cutting force, which will influence the accuracy and quality [2]. In end milling process, the thickness of the plates is reduced gradually, which makes it even more difficult to control the accuracy of machining. The end milling of such plates is complicated, where periodically varying milling forces excite the flexible plate structures both statically and dynamically and leading to significant deformations [2]. Based on this information, improvements on selecting the best cutting path strategy using end milling can be observed. Other improvement is the parameters study which will provide the information to obtain the smoothest surface roughness for thin-walled aluminum alloys and this become very important

especially in building and aircraft technology. Result obtained then will be analyzed. The parameters are surface roughness of the cutting and Machining time. The objectives of this project are:

1. To study the effect of surface roughness, machining time and machining accuracy of thin-walled aluminum alloys toward the cutting path strategies of CNC end milling machine.
2. To determine the machining cutting path strategies for thin-walled aluminum alloys in constant operating parameters by experimental method. The project is used the CNC end milling machine for cutting aluminum alloys material. The machining processes run in vertical mode. The machining process being studied is using High Speed Steel (HSS) End Mill two-flute with diameter of 4 mm of tool cutter. Different cutting path strategies by using Mastercam X MR2 software were applied to obtain the variety cutting path strategy of those parameters given. This is done in order to achieve optimum performance measures in milling cutting path strategy of thin-walled aluminum alloys fabrication. The cutting speed, feed rate and depth of cut were given in constant mode.

II. PROCEDURE FOR RESEARCH

Based from the problem statement and the objective for this project, a flow chart was used to demonstrate the project being implemented from the beginning until the end of the project as explained in Fig. 1. The project planning involves with the selection of end mills tool, material, CNC milling machine, machine parameters, machining process and strategies, safety features and report which need to be used in this project.



3. Fig. 1: Methodology Overview

Machining Setting and Programming (MASTERCAM X MR2) Based on Cutting Strategies Before running the CNC end milling machine, there are several setting need to be done in order to get the right process method for machining the product of thin-walled aluminum alloys. Mastercam X MR2 software was used in this project to select the milling cutting path strategies of each cutting process. The overview and modeling workpiece display using Mastercam X MR2 software are shown as Fig. 2 and 3. Other than that, the parameters also must be allocated to accomplish the condition of machining such as cutting speed, feed rate and depth of cut which is important in order to observe the correct parameters for the correct process. All the parameters are in a constant value of setting. Then, the experiments can be done accordingly to the machining cutting path strategies. There are seven cutting path strategies are being used for this project. The patterns of cutting paths are shown in Fig. 4:-

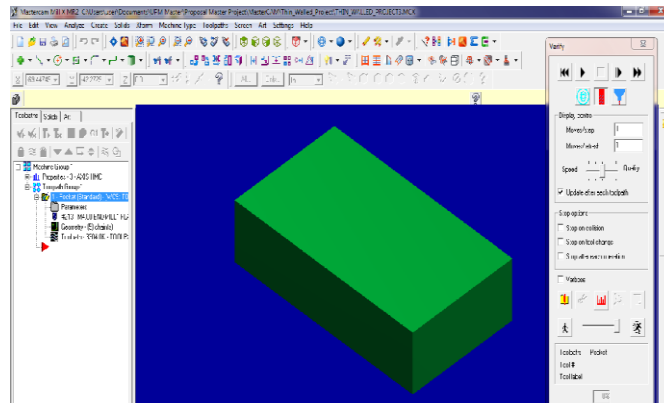


Fig. 2: Overview display of MASTERCAM X MR2 software [3]

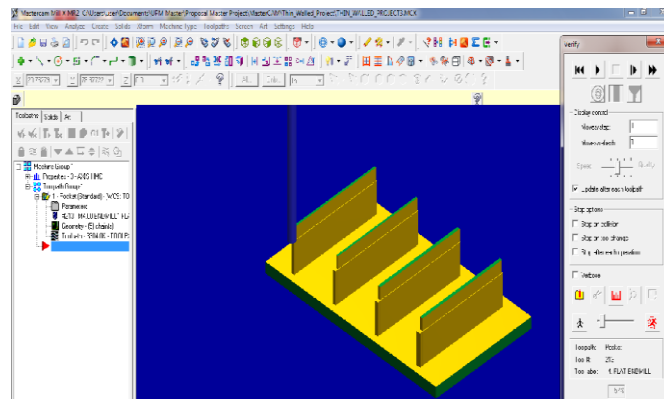


Fig. 3: Modeling workpiece display using MASTERCAM X MR2 software [3]

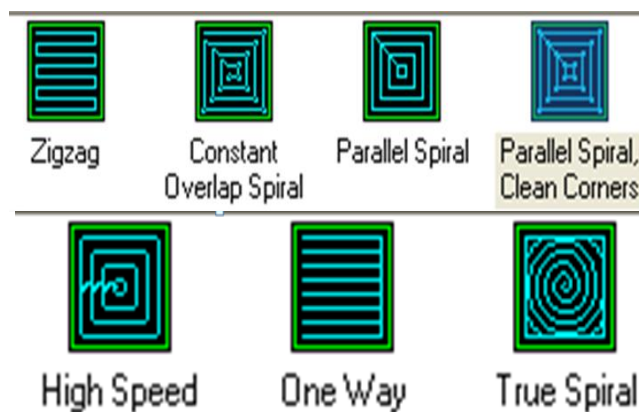


Fig. 4: Machining cutting methods in MASTERCAM X MR2 software [3]

2.2 Workpiece Preparation

The workpiece used is Aluminum 5083/H112 with dimension of 107mm X 60mm X 25mm for these experiments. The arrangement of orientation workpiece preparation and machining set up are shown in Fig. 5 and 6. Aluminum alloy 5083 contains 5.2% magnesium, 0.1% manganese and 0.1% chromium. This alloy has very good corrosion resistance which is susceptible to deterioration after prolonged exposure to elevated temperatures, moderate strength, low density and excellent thermal conductivity common to all aluminum alloys (Austral Wright Metals, Product Data Sheet).

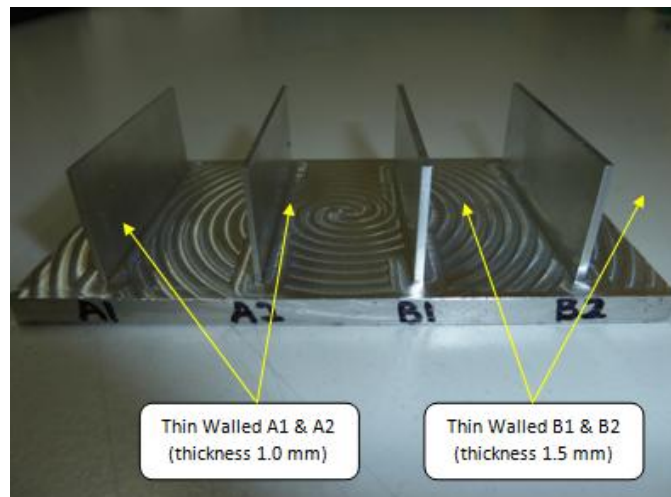


Fig. 5: The arrangement of orientation workpiece preparation

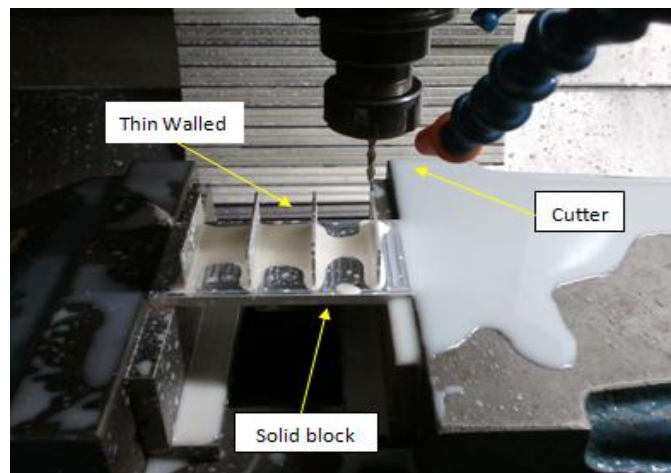


Fig. 6: Machining set up

In the tempered condition, it is strong, and retains good formability due to excellent ductility. Its weldability is a plus. It finds uses in transportation, pressure vessels, cryogenics, towers and drilling rigs, gas/oil piping, ordnance, armor plate and marine applications (Austral Wright Metals, Product Data Sheet). The authors of journal such as [4]-[7] were used the thin walled analysis by using the constant dimension of wall thickness which is 3 mm and tolerance values of 20 mm for depth of cut with ratio 3/20. Therefore, owing to the reason, this ratio 3/20 becomes 1/20 which means 1 mm for wall thickness and 20 mm for depth of cut was used in this project as shown in Fig. 7.

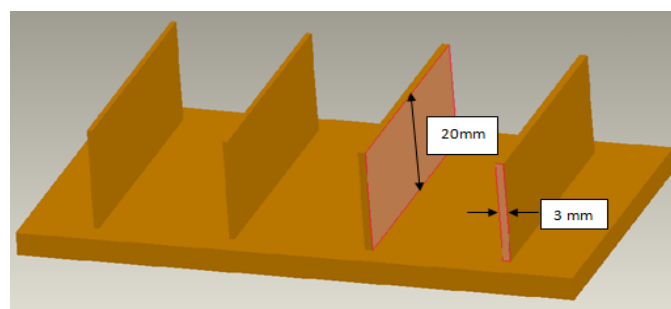


Fig. 7: The illustration of dimension ratio between 3/20 to 1/20 and 1.5/20

2.3 Data Collection: Measure Surface Roughness, Machining Time and Machining Accuracy

Measure Surface Roughness The parameter most used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging it over the entire cutoff length. Cutoff length is the length that the stylus is dragged across the surface. A longer cutoff length will give a more average value, and a shorter cutoff length might give a less accurate result over a shorter stretch of surface. It's also referred to as CLA (center line average) and AA (area average), [8]. The output of the instrument was the center-line average (CLA) roughness [8]:

$$R_a = \frac{1}{L} \int_0^L |z(x)| dx \tag{1}$$

Where,

- L = evaluation length
- z = height
- x = distance along measurement

Measure Machining Time

Machining time is calculated by applying certain basic formula, tables of variables and constants. The basic formula used is as shown below [9] but for this project the machining time are taken from the cycle time as observation from the CNC milling monitor.

$\text{Machining time} = \frac{\text{Travel of the tool necessary}}{\text{Feed} \times \text{rpm}}$	(2)
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Travel of the tool:-

This is determined from the dimensions in the actual drawing of the part to be manufactured. The necessary allowances for the tool approach and over-run for clearing the tool off the job are taken into account with the actual length of the work, to find the travel of the tool as shown in Fig. 8 below.

- If actual length of the work = *l*
- Amount of tool approach = A
- Amount of tool over run = O
- Then, travel of the tool $L = l + A + O$

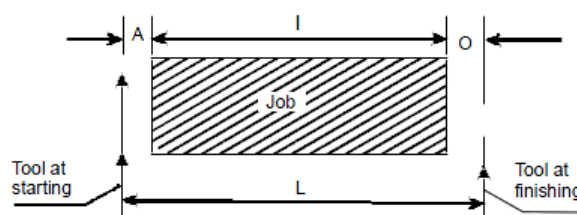


Fig. 8: Travel of the tool illustration [9]

Measure Machining Accuracy

Percent error measures the accuracy of a measurement by differentiate the measured value (E) and acceptance value (A). The percent error is calculated from the following equation below [10]:-

$\% \text{ Error} = \frac{E - A}{A}$	(3)
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Where, E is the measured value A is the acceptance value

III. Experimental Results And Discussion

3.1 Evaluation results on Surface Roughness (Ra)

There are two area of thin walled have been measured in order to obtain the values of Ra which are left and right area. At the same time, the thin walled also have been separated into four walled; wall of A1 and A2 with thickness of 1.0 mm and wall of B1 and B2 with thickness of 1.5 mm. Both surfaces are divided into five measuring point of surface roughness. The best machining strategies for achieving good surface roughness of both areas will be Parallel Spiral strategy with the average value of A1 is 1.266 μm and A2 is 1.248 μm , B1 is 1.827 μm and B2 is 1.258 μm for left area. While for the right area, the average value of thin walled A1 is 1.614 μm and A2 is 1.317 μm , and thin walled B1 is 1.410 μm and B2 is 1.677 μm . Besides that, the worst surface roughness for machining aluminum thin walled is True Spiral strategy. At this point, wall of B1 and A2 for the right area had the nastiest values of Ra which were 6.087 μm and 5.587 μm . Even as for the left area, wall of B2 and A2 have been identified receiving second place of worst Ra values which were 4.902 μm and 4.643 μm . It could be happen due to pattern of cutting strategy with considered of down cut and up cut cutting process. From here, the tool cutter of true spiral strategy have been recognized used down cut cutting process whereby the right area was observed at high repeated tool cutter touching against the wall deeply. This phenomenon is decreased with higher material removal rate as a result the surface roughness was too dire. By the way, the Ra value is still in range of accepted according to surface roughness table from Engineer's Book. All the data have been showed by referring to the Fig. 9 and 10.

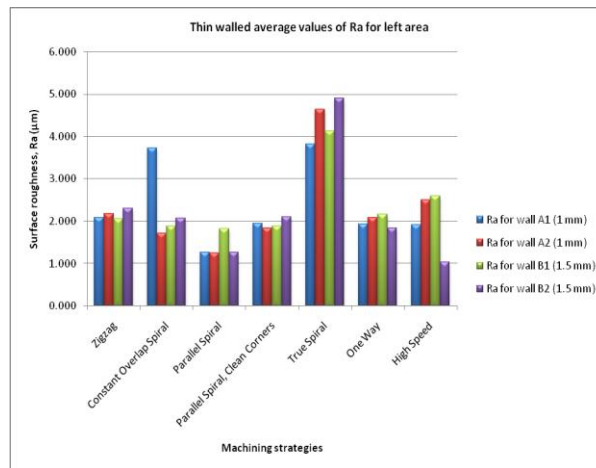


Fig. 9: Average values of surface roughness for different machining strategies (left area)

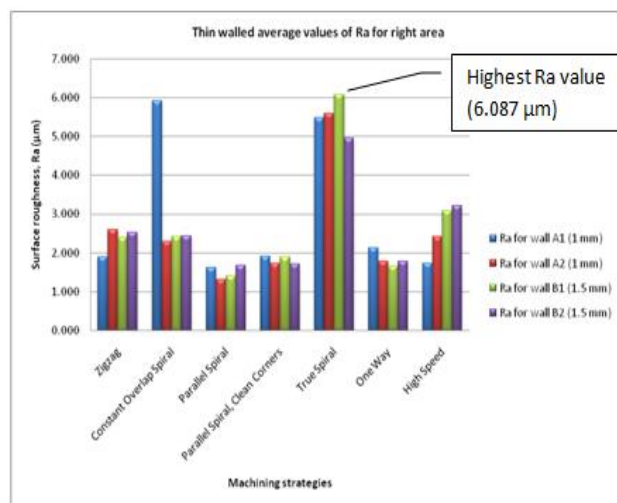


Fig. 10: Average values of surface roughness for different machining strategies (right area)

3.2 Evaluation results on Machining Time

Table II experimental results of machining time

No.	Machining Strategies	Machining Time (hour)	Machining Time (minute)
1	Zigzag	2:07:02:61	127
2	Constant Overlap Spiral	2:16:41:38	137
3	Parallel Spiral	2:05:09:77	125
4	Parallel Spiral, Clean Corners	2:23:52:96	144
5	True Spiral	4:12:22:15	252
6	One Way	5:14:49:96	315
7	High Speed	3:04:15:41	184

From the Table II, shows the experimental results of machining time in hours and minutes. The highest machining time for thin walled aluminum alloys fabrication is One Way cutting strategy with the machining time of 315 minutes. Whereby, the Parallel Spiral cutting strategy has less machining time compared to the others machining strategies with the time taken of 125 minutes. The reason is the machining pattern of Parallel Spiral strategy used down cut or down milling process in cutting condition as shown in Fig. 11. “In down milling process, the workpiece is fed in the same direction as that of the cutter’s tangential velocity. The cutter enters the top of the workpiece and removes the chip that gets progressively thinner as the cutter tooth rotates. This process produces better surface finish and dimensional accuracy as be mentioned by R.K Rajput, Manufacturing Technology”. The same as this strategy, had produced a better surface roughness with the average values of Ra are about 1.361 μm for wall A and 1.541 μm for wall B. Whereas by referring to the Fig. 12, the cutting strategies of Zigzag, Constant Overlap Spiral and Parallel Spiral Clean Corner have same types of pattern machining time without more less than 200 minutes.

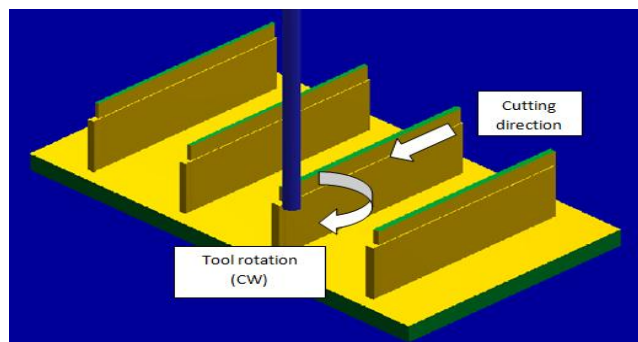


Fig. 11: The movement of tool cutter in clockwise rotation (CW) of down milling process for thin walled aluminum fabrication

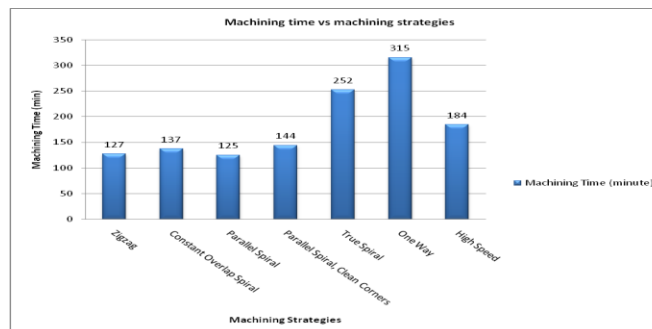


Fig. 12: Machining Time for different machining strategie

IV. CONCLUSION

This study presents a scheme to compare several machining strategies in end milling process by using visual charts. In this methodology, cutting strategies are interpreted into constraints on constant cutting conditions and cutting performance. The results show that the constraints on the surface roughness, machining time and thickness accuracy are quite important to obtain a high productivity fabrication of thin walled aluminum alloys. Evaluation of data by graph at optimal conditions was carried out. According to the results obtained, the most accurate thin walled fabrication in term of thickness accuracy within the range of specified cutting condition is true spiral cutter path strategy as reasons explained in Chapter 4. However, the outcome for true spiral cutter path was not good in surface roughness. The best machining strategies to achieve good surface roughness of upper and lower areas is parallel spiral strategy which is better than the other machining strategies. One of the reasons was that the chip stayed between the cutter and the periphery of the pocket could worsen the surface as stated by [12]. Calculation to determine the constant parameter of machining was done for the optimal factor settings of all seven cutting strategies. It is found that they are assured with recommendation by NS TOOL CO., LTD.

V. Acknowledgment

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