한국동력기계공학회지 제19권 제1호 pp. 64-69 2015년 2월 (ISSN 1226-7813)
Journal of the Korean Society for Power System Engineering http://dx.doi.org/10.9726/kspse.2015.19.1.064
Vol. 19, No. 1, pp. 64-69, February 2015

A Study on the Surface Roughness of Aluminum Alloy for Heat Exchanger Using Ball End Milling

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(Received 31 October 2014, Revision received 31 December 2014, Accepted 06 February 2015)

Abstract: Aluminum alloy is a material with a high strength-weight ratio and excellent thermal conductivity. It neither readily corrodes nor quickly weakens at low temperatures, but can be easily recycled. Because of these features, aluminum heat exchangers are widely used in aluminum alloy. In addition, the aluminum alloy used in other areas is expected to gradually increase. As a result, researchers have been continuously studying the cutting patterns of aluminium alloy. However, such studies are fewer than those on the cutting patterns of ordinary steel. Moreover, the research on ball endmilling with aluminium alloys has not received much attention. Therefore, in this study, an attempt was made to find the optimal cutting pattern among the seven cutting patterns for the machining of the commonly used aluminum alloy using ball endmilling for a heat exchanger. The optimal pattern was found by comparing the different shapes and surface roughness values produced by the seven patterns.

Key Words : Aluminium alloy, Ball end milling, Heat exchanger

1. Introduction

Aluminum is one of the most abundant metals on Earth. In most cases, it is used in the form of an alloy, which is stronger, except for foil, which is used for wrapping.

Aluminum alloy is used to make heat exchangers such as air conditioners and heaters. Its use is expected to increase in various fields. Thus, studies on the cutting theory relevant to aluminum alloy have been performed.

Aluminum alloy has a low specific gravity, a high strength, and outstanding wear resistance. Its cutting resistance is not large in the case of cutting machining. However, many build-up edges are formed at low speeds; and if the depth of cut increases, the changing pattern of the surface layer becomes very complicated. [1,2)]

End milling is the most widely used method of cutting machining. Ball end milling is the most widely used method of finishing a curved surface shape. In most cases, ball end milling is empirically assigned due to the mechanical complexity depending on the structure of a ball end mill. The cutting condition irregularly changes depending on the shape of a curved surface, which

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induces many problems in precise cutting and efficient machining.[3)]

In the machining field, demand for free-form surface machining has gradually increased. This demand has led to the abilities to design and machine complicated three-dimensional (3D) shapes, and has driven the development of the CAD/CAM software and machine tool manufacturing techniques. Due to the continuous development of the CAD/CAM software, various cutting pattern methods have been developed, and diverse tool paths can be generated. [4,5,6)]

With the development of technology, various cutting patterns have been developed. However, in production and education sites, machining is conducted based on the experience of an expert or a given manual without a comparative experiment for obtaining an optimal surface roughness.

This study aims to find the optimal cutting pattern for the machining of aluminum alloy using a ball end mill by machining the alloy through the generation of different tool paths based on the seven cutting patterns shown in Figure 2 and by comparing the shapes and surface roughness values of the machined surfaces.

2. Experiment Equipment and Method

2.1 Experiment Equipment

2.1.1 Machining Center

The machining center used in this experiment was TNV-40A (Tongil Heavy Industries Co., Ltd.).

2.1.2 Measuring Device

The surface roughness measuring device used in this experiment was model Surfcoder-F3500D (Kosaka Laboratory Corporation).

The shape-measuring device used in this experiment was model Hommel_C8000 (Hommelwerke).

Table 1 Specifications of machining center

Item		Specification
Manufacture		Tong il heavy industry
Model		TNV-40A
Table size[mm]		900 X 410
Main spindle speed[rpm]		40 ~ 4,000
Main spindle taper		NT No. 40
Main spindle diameter[mm]		Ø65
Stoke [mm]	X-axis	560
	Y-axis	410
	Z-axis	510

Table 2 Cutting conditions

	Rough cutting	Finish cutting
Spindle revolution[rpm]	2500	1800
Feed rate[mm/min]	200	220
Step over[mm]	1	0.5
Depth of cut [mm]	2	0.5

2.2 Experiment Tool and Material

2.2.1 Experiment Tool

The cutting tool used in this experiment was an uncoated general-purpose carbide end mill, which is used to machine free-form surfaces of metal molds.

2.2.2 Experiment Material and Shape

The specimen used in this experiment had a 70x70x19mm free-form surface shape. In the rough

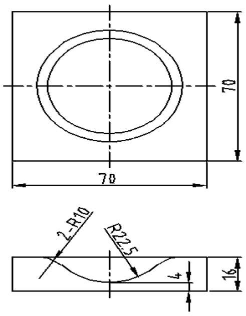


Fig. 1 Dimensions of the workpiece

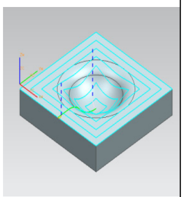
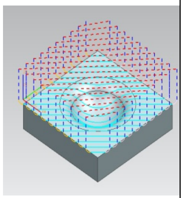
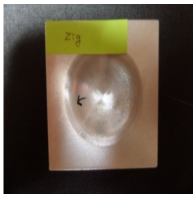
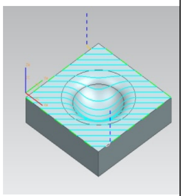
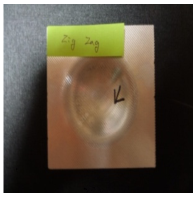
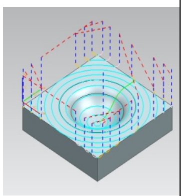
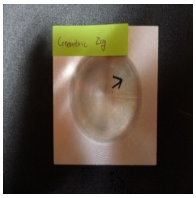
machining, a flat end mill was used, and 0.5 mm was left for finishing. In the finishing, it was machined as shown in Fig. 1, using a ball end mill.

2.3 Experiment Method

2.3.1Specimen Modeling and Tool Path Generation

Before the specimens were machined, 3D modeling was performed using the NX program, which is the CAD/CAM software of Siemens. In the program, the machining conditions were assigned, and tool paths were generated for each cutting pattern. Based on the simulation function of the program, the shapes after the machining were verified in advance, and it was checked if there was a problem. Finally, the NC codes of .the rough machining and the finishing were generated.

In the rough machining, all the specimens were identically machined in a ‘ㄷ’ form along the contour of the machining shape from the outside to the inside. In the finishing, the machining was conducted by generating tool paths using the seven cutting patterns based on down-cutting, which has been verified in a number of surface roughness studies. Fig. 2 shows the tool paths and the shapes after the machining.

	Cutting pattern modeling	Machined workpiece
Follow periphery		
	In the follow periphery method, machining is performed along the contour of modeling. A method where machining is conducted from the outside of the specimen to the inside was selected	
Zig		
	In the zig method, machining is performed as the tool proceeds. When it returns, the tool moves up to a safety height designated by a user, and goes through rapid feed. Then, it starts machining again. The cutting angle used was 45°, and the safety height for rapid feed was set to 10.	
Zigzag		
	In the zigzag method, machining is performed as the tool moves back and forth. In other words, it performs machining twice: once during proceeding and once during returning. The cutting angle applied to the specimen was 45°.	
Concentric zig		
	The concentric zig is a circular cutting pattern which gradually becomes larger or smaller from an optimal center point. This method applied the zig method, and machining is performed as the tool proceeds. When it returns, the tool moves up to a safety height	

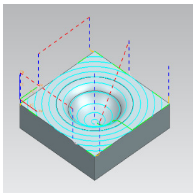
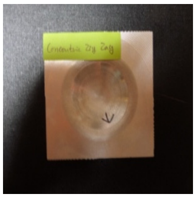
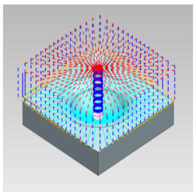
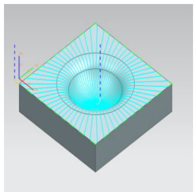
<table>
<tr><td></td><td colspan="2">designated by a user, and goes through rapid feed. Then, it starts machining again. The safety height for rapid feed was set to 10, and a method where it gradually becomes smaller from an automatically calculated optimal center point was selected.</td></tr>
<tr><td rowspan="2">Concentric zigzag</td><td></td><td></td></tr>
<tr><td colspan="2">The concentric zigzag method is similar to the concentric zig method, but it performs machining instead of the rapid feed. In other words, it performs machining twice: once during proceeding and once during returning.</td></tr>
<tr><td rowspan="2">Radial zig</td><td></td><td></td></tr>
<tr><td colspan="2">The radial zig is a linear cutting pattern that extends from an optimal center point. This method applied the zig method, and machining is performed as the tool proceeds. When it returns, the tool moves up to a safety height designated by a user, and goes through rapid feed. Then, it starts machining again. The safety height for rapid feed was set to 10, and a method where machining is performed toward an automatically calculated optimal center point was selected.</td></tr>
<tr><td rowspan="2">Radial zigzag</td><td></td><td></td></tr>
<tr><td colspan="2">The radial zigzag method is similar to the radial zig method, but it performs machining instead of the rapid feed. In other words, it performs machining twice: once during proceeding and once during returning</td></tr>
</table>

Fig. 2 Cutting pattern modeling and machined workpiece

3. Experiment Results and Discussion

3.1 Surface Roughness and Shape Measurements

The surface roughness was measured at three random spots perpendicular direction of lay on the flat part of the specimen, among the two parts of the specimen (the flat part and the curved part), and an average value was obtained. Table 3 summarizes the measured surface roughness using the center line average roughness (Ra), the maximum height roughness (Rmax), and the 10-point average roughness (Rz).

Table 3 Surface roughness results of different flat cutting patterns

Cutting pattern	Surface roughness (μm)		
	Ra	Rmax	Rz
Radial zig	1.32	9.30	8.01
Radial zigzag	1.52	11.00	9.06
Concentric zigzag	1.67	14.03	10.44
Concentric zig	1.91	14.42	11.26
Zig	2.19	15.77	12.71
Zigzag	2.20	14.20	11.70
Follow periphery	2.26	16.33	12.90

Table 4 Contour results for different concave cutting patterns

Cutting pattern	Contour (mm) Radius value	Error (mm)
Radial zigzag	22.61	+0.11
Radial zig	22.12	-0.38
Zig	22.11	-0.39
Follow periphery	22.08	-0.42
Concentric zig	22.03	-0.47
Zigzag	21.86	-0.64
Concentric zigzag	21.47	-1.03

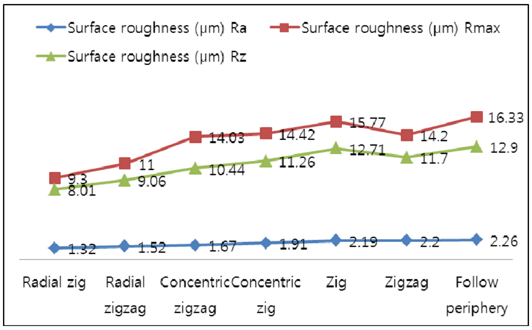


Fig. 3 Surface roughness of the cutting pattern

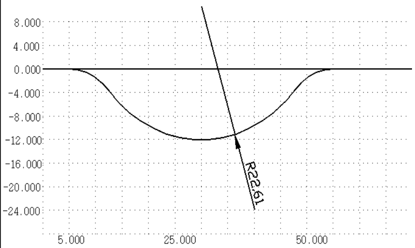
Cutting pattern	Analysis of the contour
Radial zigzag	 Radius value 22.61 mm Error +0.11 mm

Fig. 4 Measured contour characteristics of the cutting pattern

3.2 Discussion

In the case of the machining using a ball end mill, the tool path is determined using two criteria. One is the increase in the machining efficiency, and the other is the increase in the machining precision. This study considered the machining precision. The cutting patterns that had outstanding surface roughness were the radial zig and the radial zigzag. For the radial zig, Ra = 1.32 μm on the flat part; and for the radial zigzag, Ra = 1.52 μm. Thus, their surface roughness values were superior to those of the other cutting patterns.

The cutting patterns that had an outstanding shape were the radial zigzag and the radial zig. For the radial zigzag, the error was +0.11 mm in the curved part; and for the radial zig, -0.38 mm. Thus, their shape values were superior to those of the other cutting patterns.

In this experiment, scour and chipping of the machined surface occurred due to the build-up edge mentioned earlier. In particular, these phenomena were distinct in the zigzag cutting pattern where up-cutting and down-cutting were applied at the same time, rather than the zig cutting pattern where machining was conducted based on a one-way method. In the future, a study on the relationship between build-up edge and machining pattern needs to be performed.

The question of which cutting pattern is efficient needs to be answered based on the condition of the production requirements, considering the entire process. Studies on the development of a cutting pattern that can simultaneously satisfy the conflicting requirements of machining efficiency and machining precision are expected to be continuously performed.

4. Conclusion

In this study, an experiment was conducted to determine the optimal cutting pattern for the machining of aluminum alloy using a ball end mill, by machining the alloy through the generation of tool paths based on different cutting patterns and by comparing the shapes and surface roughness values of the machined surfaces. The following conclusions are drawn.

1) The measurement of the flat-part surface roughness for each cutting pattern indicated that the radial zig cutting pattern, which applied the zig pattern as a linear cutting pattern that extended from an optimal center point, showed the best machined surface, with a center line average roughness (Ra) of 1.32 μm.

2) The measurement of the curved part shape for each cutting pattern indicated that the radial zigzag cutting pattern, which applied the zigzag pattern as a linear cutting pattern that extended from an optimal center point, showed the best shape, with a concave part shape error of +0.11 mm.

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