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Performance evaluation of the developed 5-axis machining center for carbon fiber reinforced plastics

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Abstract
This paper discusses the performance evaluation of the developed 5-axis machining center for carbon fiber reinforced plastics (CFRP), which is advanced materials due to high stiffness and strength in the aerospace and automotive industry. In general, the machine is one of the critical values in 5M group; man, machine, material, method, measurement. To obtain reliable quality, the accurate machine tool is necessary. According to ISO 10791-7:2014, a series of cutting tests are conducted under finishing conditions. Then, the machined Al6061 workpiece is measured by laser 3D measuring equipment (ZS-4060, LDI), which can obtain circularity and straightness error from a standard workpiece. As a result, the developed 5-axis machining center is assessed by using the process capability index (Cpk). Futhermore, a CFRP part is fabricated and analysed based on the developed 5-axis machining center with universal jig and fixture.

Keywords: 5-axis machining center, Process capability index (Cpk), Carbon fiber reinforced plastics (CFRP), Performance evaluation

1. Introduction

In various manufacturing fields, Carbon fiber reinforced plastics (CFRP) have been used for replacing traditional materials due to its superior properties such as high strength, high stiffness, good fatigue, low density and so on. On the other hand, it can be difficult to fabricate different states compared to other conventional materials [1].

To overcome the typical failures of delamination, fiber pull-out, thermal transform, etc., various researchers have been studied machining parameters on CFRP. Uhlamann et al., studied the CFRPs machining using CVD diamond coated tool and milling tools for improving the milling process [2]. Khairusshima and Sharifah investigated the tool wear on solid carbide tool during milling process under dry and chilled air cutting conditions. They found the appropriate process parameter for machining CFRP [3]. However, few studies have been conducted to find out the process parameter of CFRP based on a dedicated machining center, universal jig, and fixture.

Therefore, in this paper, developed 5-axis machining center with universal jig and fixture was used to fabricate the CFRP. Then, the process capability index was evaluated by ISO 10791-7:2014 method with x-y-z laser calibration [4]. The experimental results showed that the drilling performance was investigated through delamination factors.

2. Process capability Index (Cpk)

Figure 1 shows that the developed 5-axis machining center (HNK) with universal jig and fixture was set up for machining CFRP, and then a series of these experiments were conducted. For the experiments, the endmill (OSG) having a diameter of 12 mm was used for fabricating the aluminum workpiece in figure 2.

According to ISO 10791-7:2014, the aluminium workpiece was KS B ISO 10791-7, M1_160. The spindle speed and feed rate were 4,000 rpm and 1,000 mm/min. The minimum quantity lubrication (MQL) of 1.75 cc/min and 4 bar was chosen as a cutting fluid.

Figure 1. Developed 5-axis machining center and universal jig and fixture

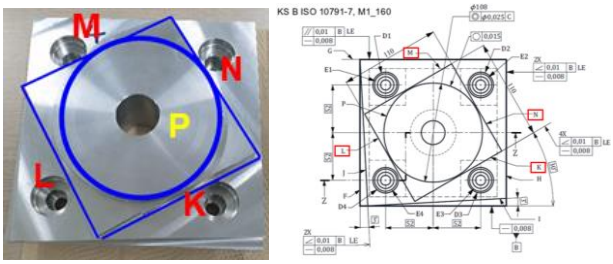

Figure 2. Aluminium 6061 workpiece for Cpk test

To measure the roundness (P) and linearity (M, N, K, L) of the machined surface, the laser 3D measuring equipment (ZS-4060, LDI) was used. Figure 3 shows the distribution histogram of (a) roundness and (b) linearity. As can be seen in Table 1, the 16 experimental results were shown in detail. The process capability index (Cpk) was a statistical value, to measure the process capability to have output within the customer's upper and lower boundary. The roundness of P was 4.18 and the

linearity of L, M, N, K were 2.52, 1.97, 1.67, 1.51. Cpk = or >1.33 indicated that the process was highly capable and met the upper and lower boundary.

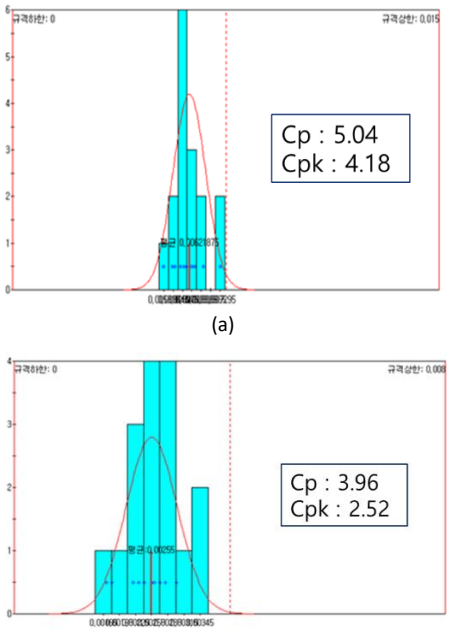

Figure 3. Cpk representative results of Al6061 workpiece about (a) roundness - P and (b) linearity – L

Table 1 Process capability index (Cpk) of machined surface

No.	Tolerances [mm]	Calculation Cpk
P	0.015	4.18
L	0.008	2.52
M		1.97
N		1.67
K		1.51

3. Experimental setup and results

Figure 1, the CFRP of 1500 x 1000 x 5 mm was consists of 3K and 12K plain weave. The built-up sequence and orientation were 3K/12K/12K/12K/12K/12K/12K/3K and 0°/90°. For the experiments, 20 of the universal jig and fixtures were fixed. The PCD drill diameter was 6 mm (Sandvik). The drilling conditions were 6,000 rpm and 0.05 mm/rev. A total of 42 holes were fabricated and measured.

The delamination is one of the failure modes in CFRP. It is generated due to the weak bonding of constituent. The ratio of maximum diameter (D_{max}) of delamination and the diameter of the drilled hole (D). Figure 4 shows the microscope image of the drilled hole at 1st and 42nd. The delamination factors were calculated by using measured holes.

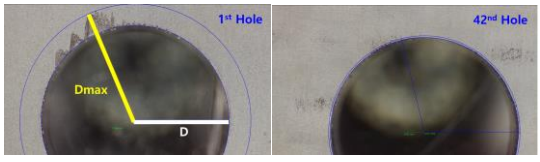

Figure 4. Microscope image of drilled holes

Figure 5 shows the results of measured delamination factors. As can be seen in Figure 5, 88 % of the total were fulfilled under the threshold which was selected according to the industry index 1.16. The others were occurred around the edge of the corner and related to the universal jig and fixture. The adsorption capacity and position of jig and fixture were some of the critical issues while machining CFRP. For those reasons, there is a need for the correlation analysis the parameter of jig/fixture and test results.

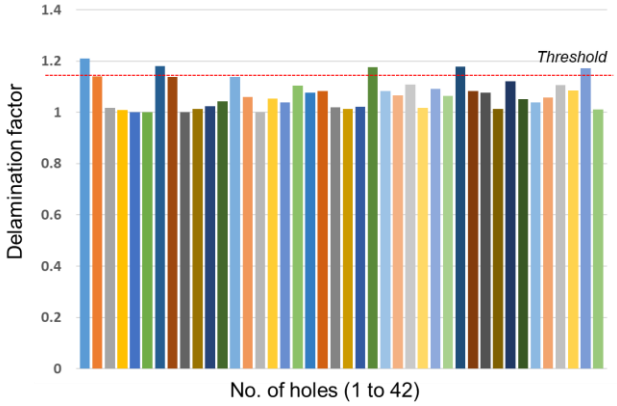

Figure 5. Results of measured delamination factors

4. Conclusion

In this paper, developed 5-axis machining center was chosen for fabricating the CFRP workpiece. To evaluate the performance of machining center, Cpk test were conducted by ISO 10791:2014 which had several parameters. Among them, the roundness and linearity of machined surface were selected and measured by using laser 3D measuring equipment. As a result, all calculated Cpk values were over 1.33 which meant that it was over 4 sigma level within customer's upper and lower boundary. For that reasons, process capability of developed machining center was verified.

Then, CFRP drilling test were conducted to verify performance of the developed machining center and jig/fixture. As a result, the most of them were content with the delamination factors based on 1.16 of industry index. For the future works, the correlation analysis of jig/fixture and experimental results will be carried out.

Acknowledgement

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