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Comparative Analysis of Aluminium 6061-T6 With Different Stock Leaves Setting on Holes True Position: A Case Study

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ABSTRACT

With the evolution of industrial technology, improved machining processes have been developed. With the expansion of machining processes, machining characteristics alter according to the tool and work materials, tools used, machining technique used, etc., increasing surface smoothness, dimensional accuracy, and tool wear. Geometric error is a problem in precision machining due to parameter settings. This research aims to analyse the effect of stock leave setup on achieving precise product hole positions and improving machining process efficiency. The substrate involved was AL6061-T6. This study involved the use of MasterCAM software for simulation analysis to predict the effectiveness of the machining process. Then, the machining process was implemented with different stock leaves of 4 mm and 1 mm using a 5-axis Mazak machine. The result reveals the coordinate measurement machine (CMM) reading is proportional to the stock leave setup. The small reading value of CMM produces better accuracy cutting in machining process. In addition, a small value of stock leave produces a hole position within the specification due to adding additional processes compared to the high value of stock leave. Thus, with suitable parameters, all machining processes can produce a good accuracy of finishing parts and meet customer requirements.

1. Introduction

Aluminium alloy is now used in many fields and is an essential raw material in CNC machining. Aluminium is one of the most adaptable, useful, and aesthetically pleasing plastic components for a wide range of applications due to the unique mix of its properties and its composites [1]. However, compared with other metals, it has low hardness and huge thermal expansion value, which makes the processing of aluminium alloy precision parts prone to product deformation [2]. The precision parts are influenced by material, production conditions, part shape, and cutting fluid performance [3]. Variations in excessive cutting force during roughing may impair the part's finish. Therefore, semi-finishing passes may be needed before completion. In this regard, the development of tool paths, the

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design of processes, and the choice of process parameters are critical for reducing total cycle time [4]. Choosing the ideal combination parameters improves part quality and lowers machining costs.

In addition, machining sequence planning plays a significant role in improving part accuracy. Strategically separating rough machining and finishing passes can minimise stress on the part [5]. The sequence and path of the cutting tool significantly impact accuracy. Moreover, cutting parameter optimisation is crucial in achieving high accuracy when machining parts. The cutting velocity, feed per tooth, and axial and radial depth of cut are the primary characteristics of the multi-tool milling process [6]. Generally, slower cutting speeds generate lower cutting forces. It reduces the deflection of the workpiece and the cutting tool, leading to more precise machining [7]. However, prolonged speeds can cause rubbing and built-up edge wear, affecting accuracy. Lower feed rates result in smaller chip sizes and less chip load on the tool [1]. This minimises tool deflection and vibration, improving dimensional control. However, very low feed rates can reduce machining efficiency. Shallower depth cuts distribute cutting forces more evenly and minimise deflection [7]. It is essential for finishing passes where achieving tight tolerances is critical. However, very shallow cuts can significantly increase machining time [8].

Besides that, in designing and using rigid and well-located fixtures to securely hold the workpiece during machining. This minimises vibration and deflection, leading to inaccuracies [9]. Use a proper coolant to reduce heat generation and chip welding, which can cause dimensional variations [10,11]. In order to ensure the appropriate application of the coolant to the cutting zone, the machining sequence needs to be planned strategically [11]. If residual stresses from machining are a concern, incorporate stress relief techniques like annealing or tempering into the process plan. Maintain a stable temperature and humidity environment in the machining area to minimise thermal variations affecting part accuracy [12]. Implementing these strategies in the machining process plan can significantly improve your machined parts' accuracy [13]. Focusing on minimising deflection, heat generation, and tool wear contributes to achieving exceptional part accuracy [13,14]. Monitoring cutting zone temperatures should be included to ensure they stay within acceptable limits. Excessive heat can lead to thermal expansion and dimensional errors [15].

Thus, achieving high part accuracy in machining is crucial for ensuring manufactured product's functionality, reliability, safety, and overall quality. It leads to significant benefits throughout the manufacturing process, from reduced waste and improved efficiency to enhanced product performance and extended lifespan. In production reality, the existing setting of stock leaves was 4 mm. However, some problems or issues are detected on the hole's true position, which can cause misalignment of electrical conductors and lead to increased resistance and signal loss. Moreover, It can reduce device efficiency, increase power consumption, and potential data errors. As an alternative, a stock leave of 1 mm has been proposed for comparison in order to improve the hole's true position accuracy. Therefore, this study aims to compare the analysis of Aluminium 6061-T6 with different stock leave setups on the 4-hole's true position. The effect of additional feature process settings on roughing machining operations will also be investigated. Hopefully, improving the hole's position can help production save time assembling another part without additional work.

2. Methodology

In this study, different machining parameters used in simulation analysis and actual machining process for Aluminium 6061-T6 were stock leaves of 4 mm and 1 mm. This stock leaves setting was set before the finishing process. On the contrary, stock leaves of 1 mm have an additional feature added during roughing. Thus, a comparison between stock leave settings of 4 mm and 1 mm was investigated.

2.1 Simulation Process

This study uses Mastercam (computer-aided manufacturing) software with version 2024 to simulate machining parts where the interface can be seen in Figure 1. The simulation can help check for collisions, verify the toolpath, and estimate the machining time. The simulation process only shows a stock leave of 4 mm because the same process flow undergoes for 1 mm.

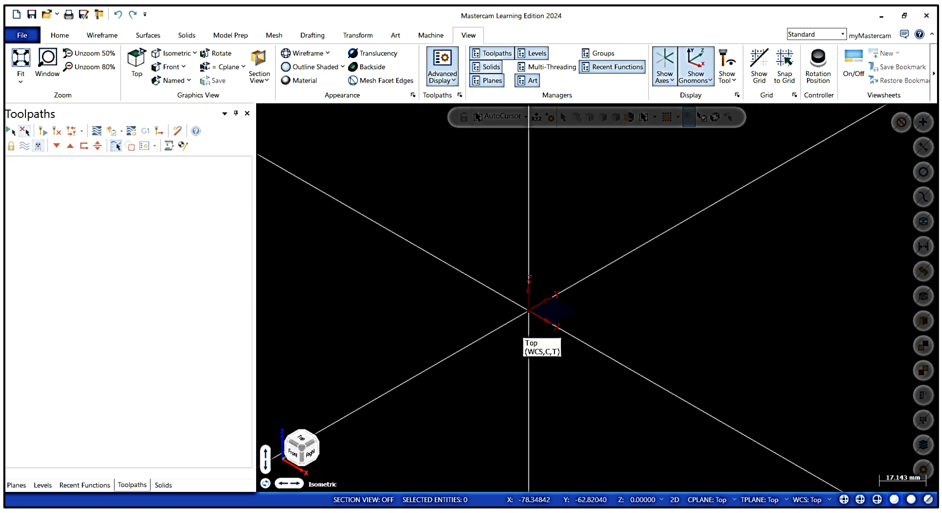


Fig. 1. Mastercam interface

2.1.1 Tool path selection

There are a few ways to view the toolpath in Mastercam. The most common way to use the Toolpath Manager is by clicking on the Toolpath Manager tab on the left-hand side, as illustrated in Figure 2. Then, a list of all the tool paths created for the current part was opened. The tool used and cutting movement were observed in the tool path and then displayed in the graphics window, as represented in Figure 3. Clicking the tab machining operation (OP) in a red-dotted box will show the tool path overview.

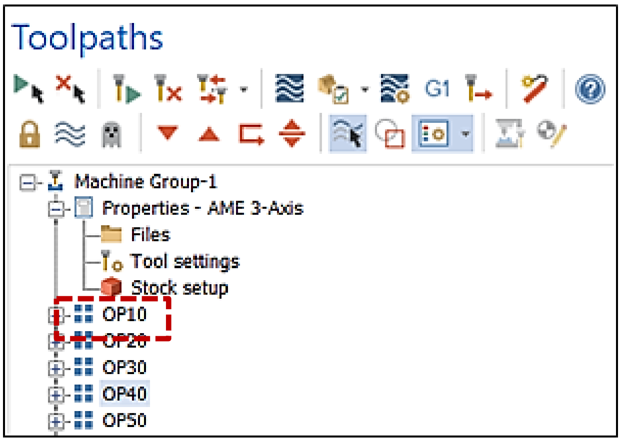
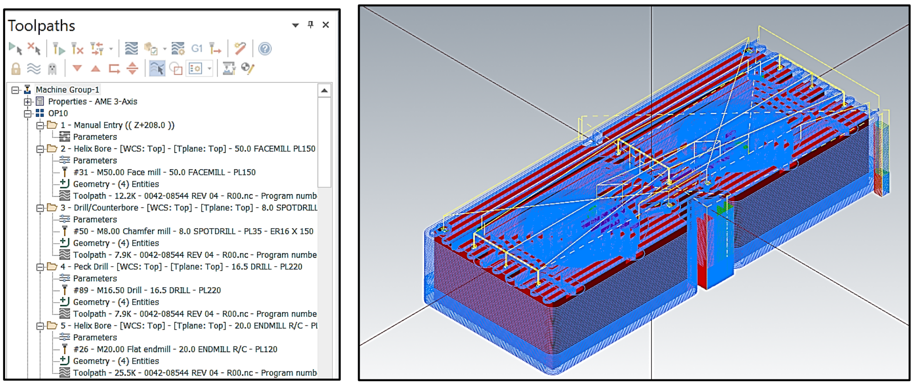


Fig. 2. Selection of toolpath manager



(a) (b)

Fig. 3. Tool path manager (a) Tool path overview (b) Displayed graphic

2.1.2 Feed rate and spindle speed setting

Checking cutting parameters in Mastercam ensures that the CNC machine is programmed correctly and that parts are machined to the desired specifications [16]. The toolpath tab on the left side is also shown in Figure 4 to show every tool parameter, tool path type, type of tool/holder, cut parameter cutting geometry, and tool path simulation. After clicking the parameter, the cutting parameters for the toolpath, including the feed rate, spindle speed, and depth of cut, can viewed and edited. Then, the cutting parameters for the tool path were displayed as presented in Figure 5.

Fig. 4. Cutting parameter selection

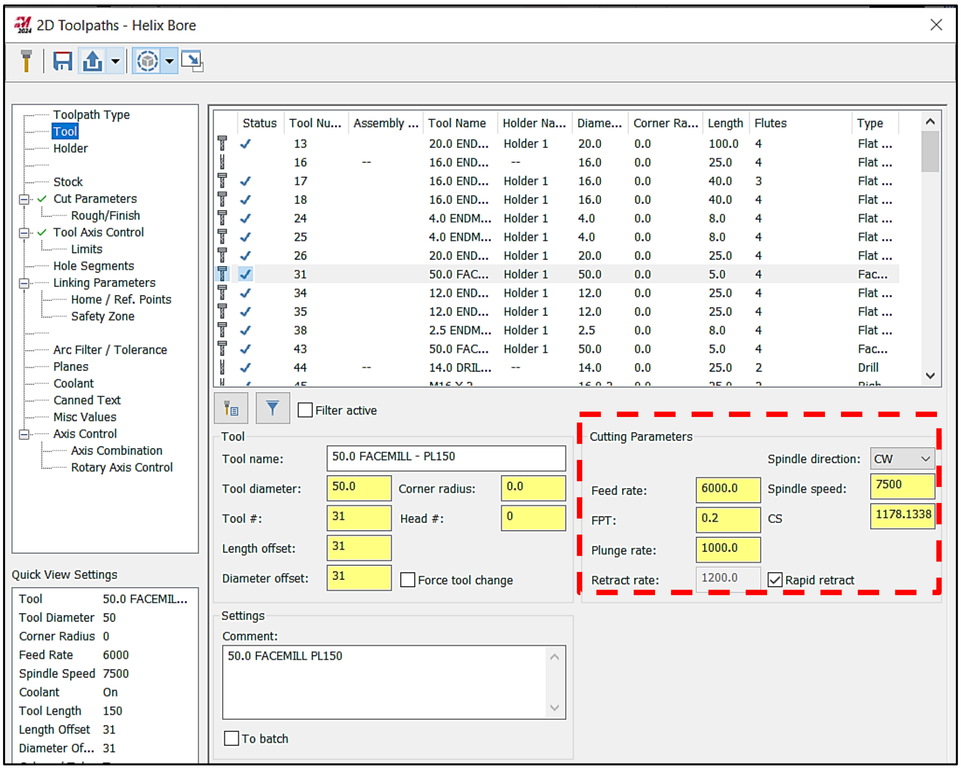


Fig. 5. Cutting parameters of the setting box

2.1.3 Stock leave wall/floor setting

The stock leave wall/floor is the material left on the part after the completed toolpath. This is important for operations such as milling and turning, where leaving a small amount of material on the part is essential to avoid cutting through it thoroughly. The stock leave wall is the material left on the part after the roughing operation [17], as represented in Figure 6. Setting the stock to leave the wall and floor will help to achieve the desired surface finish. The stock leave wall will provide a base for the finishing operation, and the floor will determine the depth of the cut that will be made during the finishing operation. A larger stock leave wall will generally produce a rougher surface finish, while a smaller one will achieve a smoother surface finish [18]. A deeper floor will result in a deeper cut and a rougher surface finish, while a shallower floor will result in a shallower cut and a smoother surface finish.

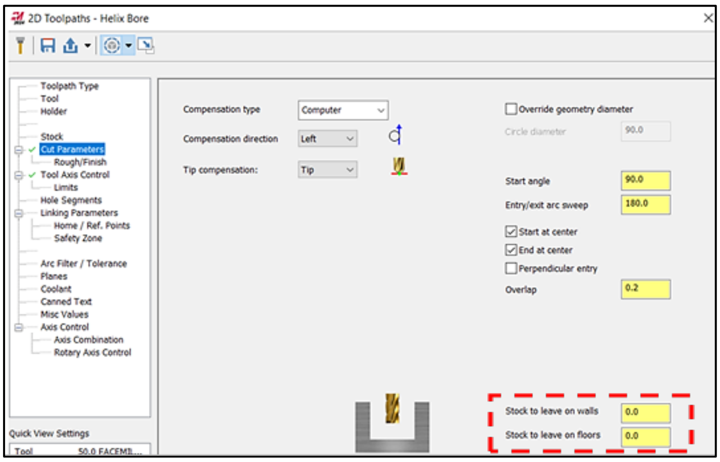


Fig. 6. Setting the stock to leave on walls and the floor

2.1.4 Depth of cut setting

For finishing operations, it is preferred to use a smaller depth of cut to achieve a smooth surface finish. A smaller cut depth will ensure the cutting tool does not remove too much material [19]. The desired surface finish is also a factor in determining the depth of cut. Thus, a rougher surface finish will require a larger depth of cut, while a smoother surface finish will require a smaller depth of cut [16]. The setting for depth of cut is 2.5mm, as shown in Figure 7.

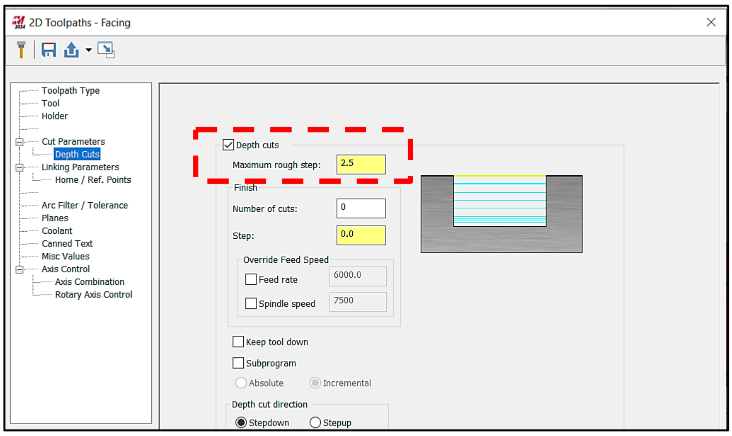


Fig. 7. The depth of cut setting

2.2 Sample Preparation

In this study, the substrate used was Aluminium 6061-T6, as shown in Figure 8. A mill certification for a substrate is a document that provides information about the chemical composition, mechanical properties, and other characteristics of a specific batch of Aluminium 6061-T6 alloy to ensure that the material meets the required specifications, which can be seen in Table 1.

Fig. 8. The aluminium 6061-T6 substrate

Table 1
The raw material characteristics

Material type	Aluminium 6061-T6
Standard	ASTMB209
Heat lot no.	TXG2303W60955
Tensile strength (MPa)	290
Yield strength (MPa)	248
Elongation %	10
Brinell hardness (HB)	95
Stretching ratio %	3

The Mazak machine with a 5-axis vertical milling/turning centre was used to machine the Aluminium 6061-T6. The cutting fluid was used as the primary coolant [11]. It will help to reduce heat generated during machining, reduce friction, and prevent overheating of the workpiece and the cutting tool [20]. Then, the routine of cutting tool inspections was regularly checked to ensure that any signs of wear, damage, or defects were detected by using a magnifying glass or a high-resolution camera model to examine the cutting edges, surfaces, and shank thoroughly [21]. Besides that, the machine's temperature is recorded every 4 hours to avoid excessive heat that can harm the machining process, such as tool wear, dimensional errors, surface finish problems, and residual stresses [22]. After the machining process was completed, the 4-hole position was measured using a coordinate measurement machine (CMM) to check whether the holes' dimensions affected the hole specification. Figure 9 shows a hole offset due to a misalignment during assembly, where the hole's true position is out-of-specification, possibly because of stock leave setup and deformation. Due to these misalignment holes, it will affect the standard part that cannot be assembled.

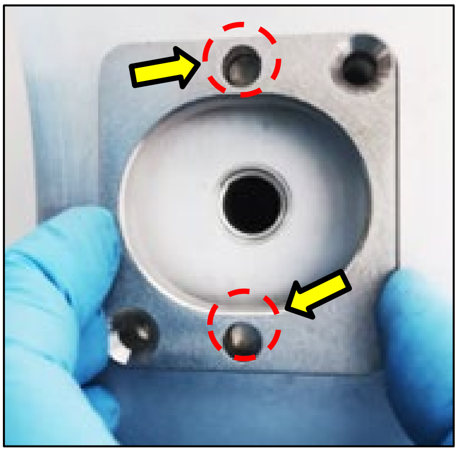


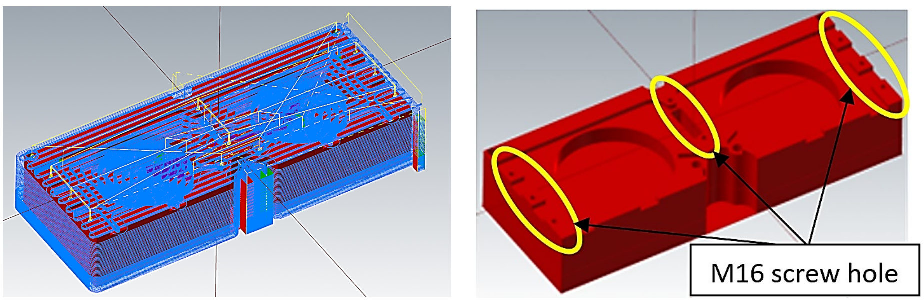
Fig. 9. Hole offset due to true position is out of specification

3. Results

3.1 Simulation Analysis

The roughing OP1 (machining operation 1) stock model simulation has been developed using Mastercam. Figure 10 presents an isometric view using 3rd angle projection. This roughing operation removes material from the inside of a part/desired features [23]. It makes the clamping screw M16 set up for the next operation setup as shown in Figure 10(b). The 5-axis machine will involve the x-axis, y-axis, z-axis, B-axis (angle of rotation spindle) and C-axis (angle of rotation table) [24]. Moreover, this operation involves vertical milling only. After that, the cutting process for four chamber features, including an outer profile, two big holes left and right, centre slopes and a top profile was implemented. Stock leaves settings for finishing operation are 4 mm per side, as presented in Figure 11. The stock model shows the part overview after finishing machining for every machining operation (OP).

This process of machining OP2 (machining operation 2) is set to remove material from the inside of a part/desired features and make the clamping screw M16 to set up for the next operation. In addition, this machining process still undergoes roughing where the material is removed for the bottom side, toolpath overview as presented in Figure 12(a). Furthermore, this OP2 operation was set to cut four main features for the chamber, including inside two holes, a slot pocket, an outer profile and two bosses. Stock leaves for finishing operation is 4 mm per side. Stock leave settings for finishing operation are 4mm per side, as illustrated in Figure 13.



(a) (b)

Fig. 10. (a) Tool path overview (b) Stock model for machining OP1

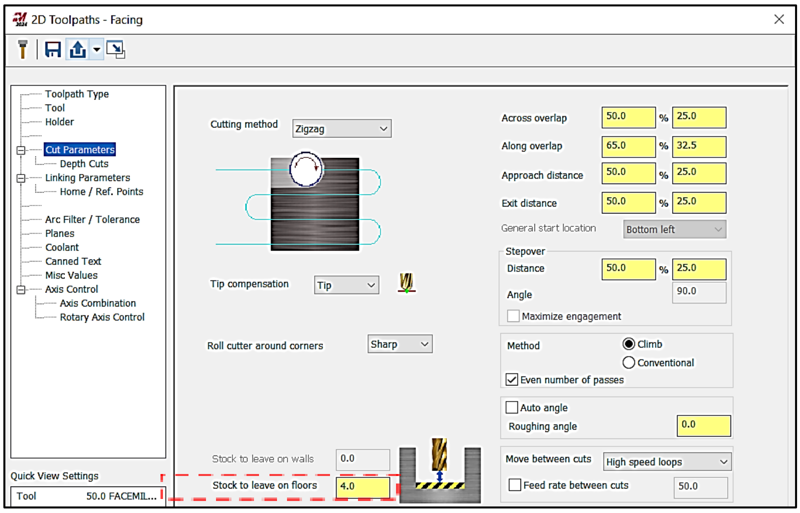
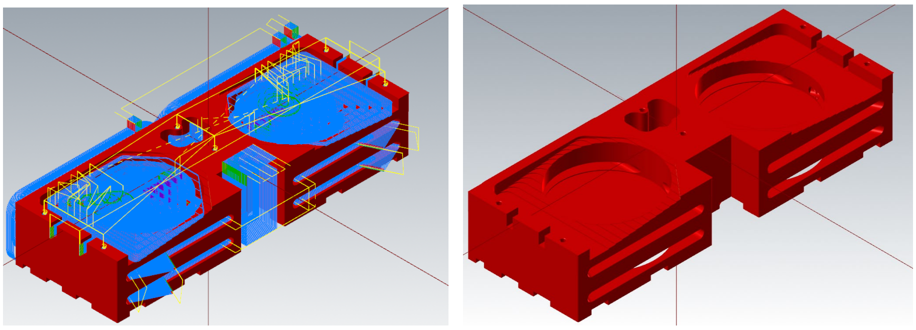


Fig. 11. The stock leave for the floor during machining OP1 is 4 mm


(a) (b)
Fig. 12. (a) Tool path overview (b) Stock model for machining OP2

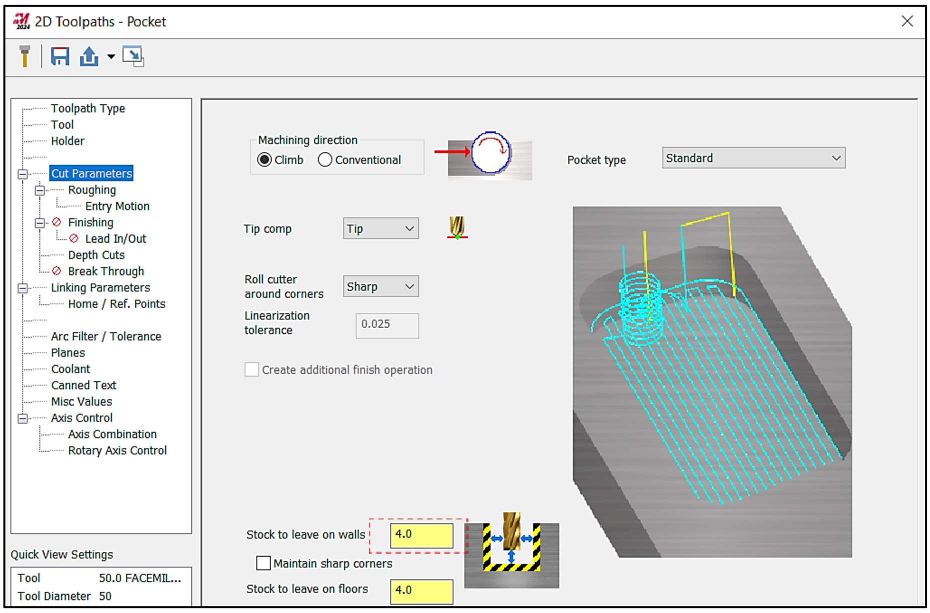
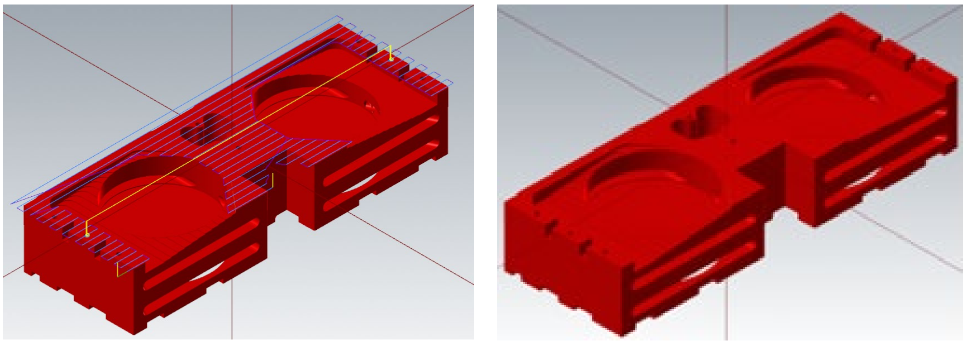


Fig. 13. The stock leave for the floors and walls during machining OP2 is 4mm

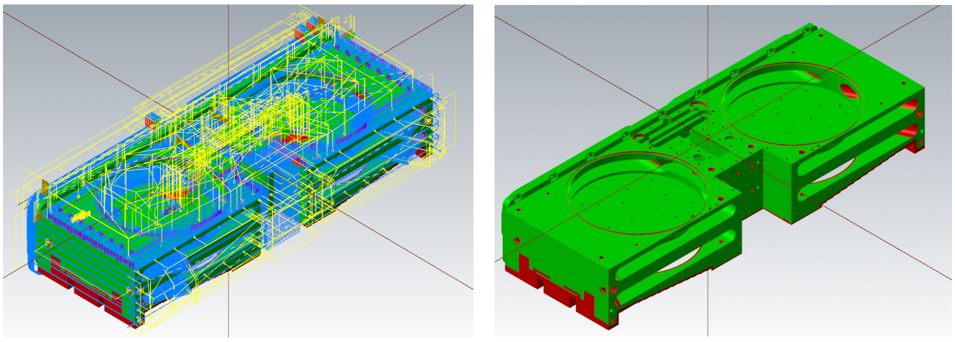
The following process is a semi-finishing process where machining OP3 (machining operation 3) is involved in making a control hole guide pin as a locating pin during setup on the fixture at Machining OP4 (machining operation 4), as illustrated in Figure 14. The finishing process through OP4 was implemented until the desired dimension for the top and all sides was achieved, as seen in Figure 15.

The final finishing of OP5 (machining operation 5) was employed as the last stage of the process Figure 16.



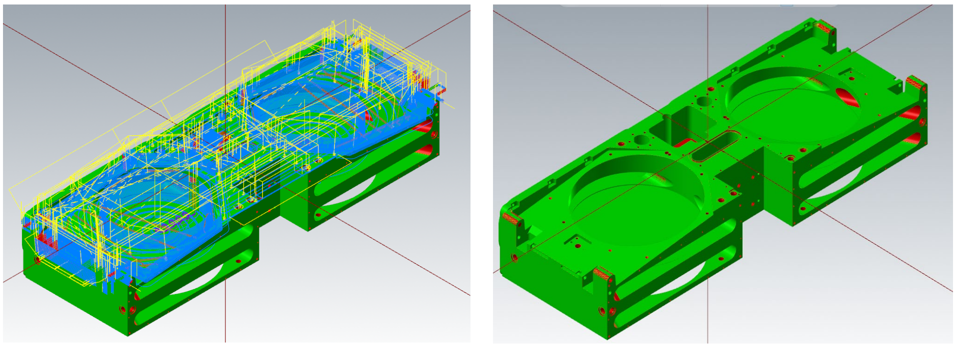
(a) (b)

Fig. 14. (a) Tool path overview (b) Stock model for machining OP3



(a) (b)

Fig. 15. (a) Tool path overview (b) Stock model for machining OP4



(a) (b)

Fig. 16. (a) Tool path overview (b) Stock model for machining OP5

3.2 Effect of Different Stock Leave and Additional Features Process

After the simulation of stock leaves, 4 mm was completed, and 1 mm was started to simulate using the same process flow and setting. Other cutting parameters involved such as spindle speed, depth of cut and feed rate, are fixed. The comparison setting between a stock leave of 4 mm and 1 mm is shown in Table 2. As mentioned before, stock leave of 1 mm has two additional processes after roughing the top side and outside profile: T-slot cutter roughing and feature 1 and 2 roughing. Both substrates of stock leave setups are then measured using a coordinate measurement machine (CMM) to ensure that the 4-hole's true position follows the specification.

Table 2
Difference stock leave setup and additional features process for 1 mm

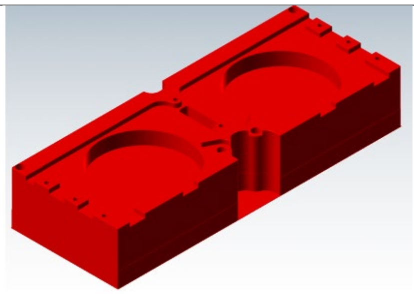
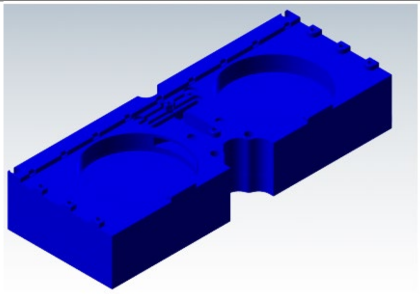
OP	Stock leave 4 mm	Stock leave 1 mm
		
OP1	Clamping hole	Clamping hole
	Roughing top side and outside profile	Roughing top side and outside profile
	N/A	T-slot cutter roughing
	N/A	Feature 1 and 2 roughing
OP2	Roughing bottom side and side pocket	Roughing bottom side and side pocket
OP3	Cleancut	Cleancut
OP4	Finishing top side	
OP5	Finishing bottom side	

Figure 17 reveals the graphical view for coordinate measurement machine (CMM) reading between a stock leave of 4 mm and 1 mm for the 4-hole position. The observation shows that the CMM readings for the affected 4-holes decrease when the stock leave setup is reduced. Thus, the CMM reading for stock leave of 1 mm shows a lower value than 4 mm. The reading of 4 mm significantly increased by almost 120 per cent on hole 3 and kept expanding on hole 4, as represented in Figure 17 and Table 3. The CMM result in geometric dimensioning and tolerancing (GD&T) for 4 holes selected by measuring the true position of the holes (Table 3). This result shows an increment due to process roughing already removing as many features and reducing the part's deformation.

Figure 18 shows the CMM value for X-coordinate and Y-coordinate for Hole 4. The result revealed that the 4 mm stock leave is out of the circular specification area and is supposedly in the circular specification area. Meanwhile, for stock leave of 1 mm, the hole is in the circular specification. It shows that having 1 mm of stock leave and the added features process during roughing process will meet the dimensions in-tolerance per the specification limit of the hole's true position of 0.025 inches and improve the accuracy of the part after machining process. Thus, the true position of the 4-holes affected might be because the stock leave is too thick and affects the accuracy of the positioning hole. Plus, the part might be deformed due to too much stock left during the finishing process [25-26].

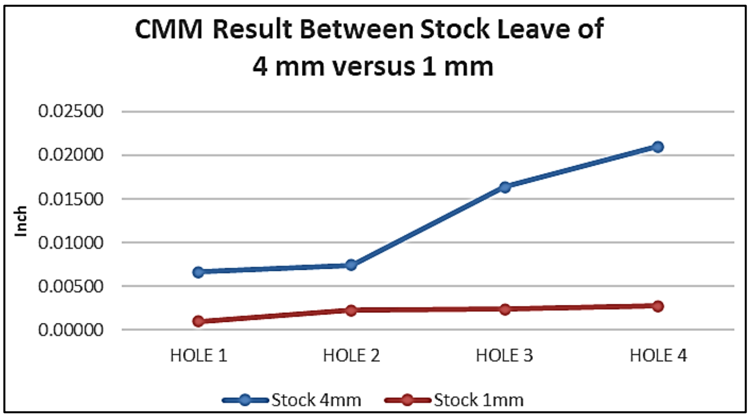
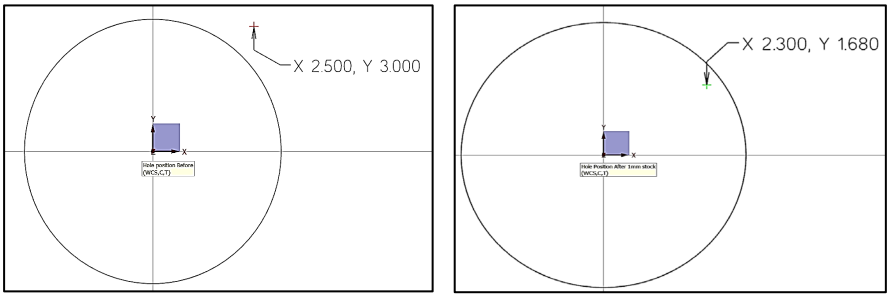


Fig. 17. Graph CMM reading of stock leave of 4 mm and 1 mm

Table 3
CMM result for the affected 4 holes

Feature	LSL (Lower specification limit)	USL (Upper specification limit)	CMM result	
			Stock 4 mm (inch)	Stock 1 mm (inch)
HOLE 1	0	0.003	0.00663	0.00098
HOLE 2	0	0.003	0.00742	0.00226
HOLE 3	0	0.003	0.01639	0.00235
HOLE 4	0	0.003	0.02100	0.00276



(a) (b)

Fig. 18. CMM measurement of X and Y coordinate for hole 4 position (a) 4 mm (b) 1 mm

3.3 Actual Setup for Aluminium 6061-T6

Before the machining process, a fixture to raise the part of 300 mm needs to be used due to the limitation of the spindle head colliding with the table [27]. The fixture setup of the part is shown in Figure 19. For OP1 and OP3, the same setup uses a direct machine table, as shown in Figure 20. There are only three guiding pins, and a side clamp is needed. This similar setup applies to stock leaves of 4 mm and 1 mm.

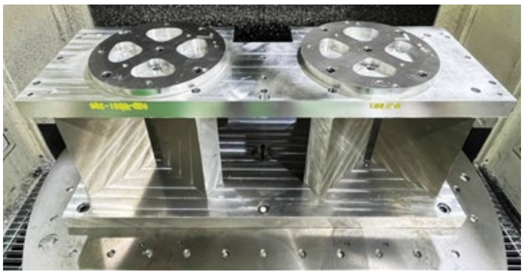
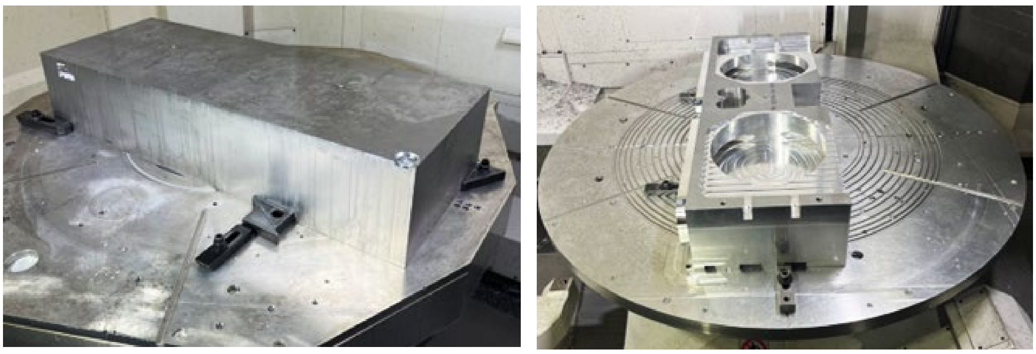


Fig. 19. Fixture of the part during machining

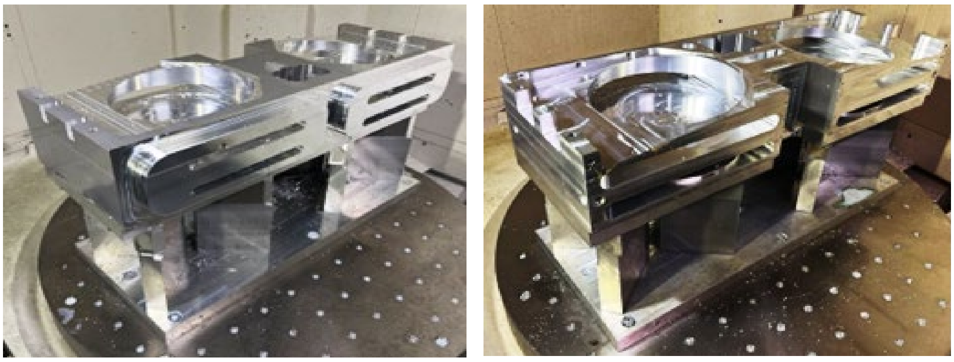


(a) (b)

Fig. 20. Part setup (a) Machining OP1 (b) Fixture of the part during machining OP3

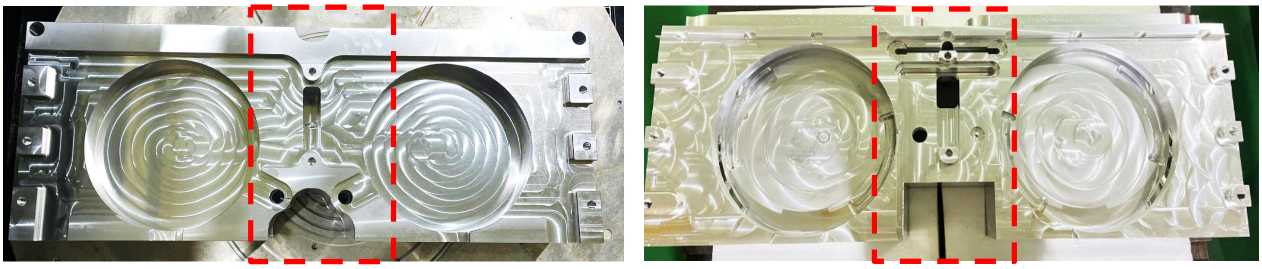
Besides that, OP2, OP4, and OP5 used a fixture riser to encounter the limitation of the spindle head that would collide with the machine stage, as shown in Figure 21. Hence, a fixture riser makes the process easy for every side.

The 1 mm stock leave significantly differs due to the added features process for machining OP1, as represented in Figure 22. The appearance is different due to additional feature cuts and holes. The purpose of this process is to release the stress of the part after finishing machining OP1. During roughing, a lot of cutting force is applied to the part to remove the targeted material before finishing. Thus, the part needs to cool down before performing the finishing process. It might be distorted if the stock wall is too thick and the material is not removed as much as it can be cut before finishing. CMM data shows that reducing the stock wall and adding this process helps the hole position get the target location per programming settings. Therefore, removing stock before finishing process and adding additional features during roughing process will improve product accuracy. Parts adhering to precise dimensions and tolerances fit together seamlessly and function as intended. This improves overall product performance with reduced friction, better wear resistance, and optimal mechanical properties. Consistent part accuracy allows for smoother integration with automated assembly lines and processes. Improved part performance and reduced need for rework contribute to a more sustainable manufacturing process.



(a) (b)

Fig. 21. Fixture of the part during machining (a) OP4 (b) OP2 and OP5



(a) (b)

Fig. 22. Actual part finish of machining OP1 with stock leave (a) 4 mm (b) 1 mm

4. Conclusions

In conclusion, a simulation study was used to predict the actual machining process for Aluminium 6061-T6. A comparison between a stock leave of 4 mm and 1 mm was investigated. From observation, the CMM reading is proportional to the stock leave setup. The small value of CMM was consistent with the accuracy part of machining process. With two additional processes added for 1 mm, the position of the hole is within the specification. The accuracy of the part during the roughing stage was improved compared to 4 mm. This will lead to enhanced overall product performance, reduced cost of rework, a smoother integration of the production assembly line and support sustainability of the manufacturing process.

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