INVESTIGATION OF HOLE QUALITY AND TOOL WEAR IN HIGH-SPEED DRILLING OF AL 7050

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ABSTRACT

This paper investigated the feasibility of drilling aluminum 7050 with enhanced cutting speed. Two identical tools and two identical Al-7050 work-piece plates were utilised during the experiment. Wet cooling drilling on both conventional and high cutting speeds was conducted to compare the results. A total of 338 holes were drilled towards the end of the experiment. Tests for tool wear, borehole diameter, and hole quality were carried out to observe the different drilling performances by drilling with different cutting speeds. The result shows that the proposed high speed drilling produced better diameter accuracy, better surface roughness but poor exit burr hole tendency.

KEYWORDS

Hole quality; tool wear; burr; enhanced-speed drilling; surface roughness; hole diameter

1. INTRODUCTION

Drilling with a conventional tool at a higher cutting speed are known to bring a certain level of implication towards hole quality and tool life [1-7]. Moreover, recent developments of aerospace aluminum alloy (70xx series) work piece material constituent and improvement in strength might also leads to this implication[8,1]. Generally, aluminum alloy tends to adhere to the cutting tool surface and burrs are formed inside the holes, thereby leading to rapid tool wear[9]. This tool damage is caused primarily by the formation of adhesion layers and built-up edges (BUE), causing a reduction of tool life[10]. As drilling operation productivity becomes an issue, enhancing drilling cutting speed becomes an attractive solution. However, it would possibly risk holes quality and tool life.

A number of researchers have investigated the effect of enhancing cutting speed with respect to hole quality and tool wear in drilling different series of aluminum alloy. However, clear resources from literature references for a particular combination of wet condition cutting of aerospace aluminum alloy (70xx series) at a certain cutting speed were found unavailable. Nouari et al reported that very high-speed drilling (V_c=300m/min)of Al2024 in dry drilling condition increases torque and thrust force which leads to the presence of a relatively large amount of friction, rapid heat generation and chip welding. This leads to a rapid growth of adhesion layers and built-up edges (BUE), and also chemical species diffusion. Thus resulting on rapid tool wear rate which rapidly reduces the quality of the holes produced[1,5]. At the same paper, it was reported that for each different type of cutting tools tested, hole diameter deviation was high at low cutting speeds (V_c<65 m/min), yet found minimum when drilling at 65m/min and inclined when speed was increased beyond that. Astakhov reported that generally, excessive drill cutting speed causes excessive wear of the drill periphery corners[11].

On the contrary, a few authors including Trent [10] and Aurich et al [12] suggested that machining with an increase in cutting speed reduces the formation of BUE. Farid et al mentioned that the decreasing amount of BUE formation was caused by the insufficient time of the deformed chips to weld to the cutting edge, hence producing better surface finish. Moreover, thrust force decreases with increasing cutting speed[2]. Chiffre et al identified the height and the width of the burr were reduced at both entry and exit sides when a higher drilling cutting speed was applied on drilling Al alloy sheet[4]. It was addressed by Abdelhafeez et al that a highly non-linear relationship between exit burr height and the cutting parameters exist which is represented mathematically by the second order regression [13].

As these literatures suggest different findings for different levels of high cutting speeds and machining condition of drilling aluminum alloy, thus it is necessary to have a clear knowledge of the hole quality and tool wear of a certain cutting speed. Within this present paper, an experiment was performed to investigate this. The influence of enhancing cutting speed on hole surface roughness, borehole diameter deviation, holes exit burr formation, and tool life are analyzed. A relationship between tool-machining temperature and tool life is established.

2. Experiment Setup

2.1 Work-Piece Material

The work-piece drilled in this research was aluminum alloy AA 7050-T7451 plate with material composition given in Table 1. The material was provided by Airbus in the form of a square plate of size 458mm (length and width) x 30 mm (height). This material was then cut in half into two separate work-pieces, each of which will be drilled during different experimental setups.

Table 1 Chemical composition (wt%) of an AA-7050-T7451 [14]

Component	Wt. %
Al	87.3 - 90.3
Cr	Max 0.04
Cu	2 - 2.6
Fe	Max 0.15
Mg	1.9 - 2.6
Mn	Max 0.1
Si	Max 0.12
Ti	Max 0.06
Zn	5.7 - 6.7
Zr	0.08 - 0.15
Other, each	Max 0.05
Other, total	Max 0.15

2.2 DRILLING TOOL

Two new identical drill tools manufactured by Klenk ($\varnothing 7.811\ HS0930 - 15\ 008\ CHS1938 - 4\ 32/15$)) were also supplied by Airbus for the experiment. The drill was identified as an uncoated carbide drill tool and measured as having a geometrical specification as follows: flute length of 60 mm, diameter of 7.811 mm, two conventional cutting edges, with relatively light web thickness, point angle of 140^{o}, helix angle of 20^{o}, with a countersink diameter of 15 mm and counter sink angle of 50^{o}. The drill tool also had two internal cooling channels, which were irrelevant within this research since no through-coolant supply was utilised. Figure 1 feature images of the drill tool.

Figure 1 (a) Twist carbide drill tool utilised in this experiment (b) top view

2.3 EXPERIMENTAL EQUIPMENT

The drilling tests were executed on a HAAS VF-2SS (super speed) vertical machining centre. This machine was utilised due to its spindle speed rotation capability up to 12,000 rpm. The coolant utilised was Blasocut BS25-MD. The drilling holes layout was designed as staggered holes with 1 mm gap between holes to assure that the gap between holes was minimal; thereby achieving the maximum number of holes to be drilled, which on this plate was achieved as 338 holes. An LK G90C CMM was used to measure the diameter of the drilled holes. It was equipped with a Renishaw PH10M touch probe with a 40mm stem length and 2mm stylus ball diameter. This probe was suitable to measure the diameter in different depths of the drilled holes. The measurement accuracy of this CMM is $\pm$10µm. A Taylor Hobson Surtronic 25 surface-roughness tester was utilised to measure the drilled holes wall surface-roughness. The surface-roughness tester has a 5µm tip radius with 0.01 µm resolution. A Jenoptik ProgRes C10 plus optical microscope and Progress CapturePro 2 software package was used to magnify and measure geometrical properties of the drill tool and also utilised to identify the growth of tool wear on the cutting edges that occurred as drilling commence. A point to point measurement via pixel size and count was conducted in order to obtain the actual length of the captured image on the screen. A Keyence VHX 500 digital microscope was utilised to observe the hole exit burr quality of the drilled hole and also to observe a cutaway view of the drilled surface holes wall. K-type thermocouples was used to determine the temperature during a number of drilling cycles. For this, a section of one of the work-piece plates was cut off, machined to provide square faces and pre-drilled with a number of holes to later accommodate the thermocouples.

2.4 EXPERIMENTAL PLANNING

The experiments were planned and conducted to evaluate and analyze the following parameters:

- Hole diameter, hole surface-roughness, exit burr formation in relation to tool life

- Cutting temperature (recorded in the proximity of the drilled hole)

The experiment was chosen to be performed at two different operation setups. The first setup was a series of drilling 338 holes. A periodical stop for every 16 holes drilled was performed to remove the tool bit from the CNC drilling center to measure its tool wear progression. The second experiment setup was a temperature measurement by drilling with a new and worn tool at both speeds, 3 holes each. During the experiment, the feed rate remains constant at 0.095 mm/rev, with stroke at 39 mm. Table 2illustrates the other cutting parameters set within the experiments.

Table 2 Experimental cutting parameters

	Experimental setup 1 Hole quality and tool wear measurements		Experimental setup 2 Temperature measurement	
Parameters	Conventional speed – Tool 1	Enhanced speed – Tool 2	Conventional Speed – Tool 1	Enhanced speed – Tool 2
Cutting speed [rpm]	2959 (73m/min)	6543 (161m/min)	2959 (73m/min)	6543 (161m/min)
Feed velocity [mm/s]	4.7	10.4	4.7	10.4
Cycle time/hole [s]	8.3	3.8	8.3	3.8
Number of holes	338	338	3 by new tool, 3 by worn tool*	3 by new tool, 3 by worn tool*

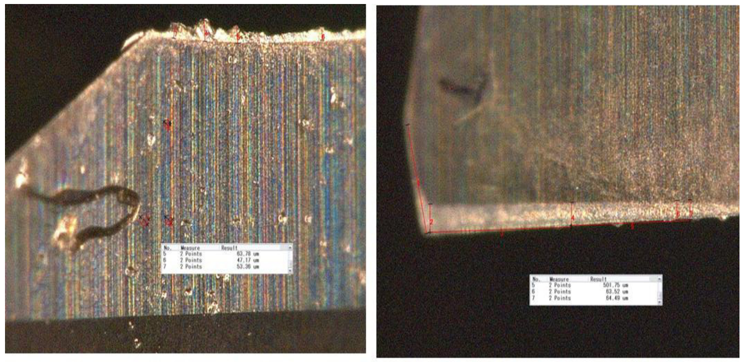
* worn tool after drilling 338 holes

Whilst the tool wear measurements were conducted “on-line”, i.e. the drilling process was interrupted so that the tool could be taken out from the spindle and measured. The inspection of the hole quality (diameter, surface roughness, exit burr formation) was conducted “off-line”, i.e. once the entire plate had been drilled and could therefore been taken off the machine. Hole diameter measurements were conducted with an interval of every 16 holes drilled, to align with the implication of tool wear rate. For each holes being measured, measurement was taken at three different depths, -6.3mm (below the cone), -16.3mm (middle section), and -26.3mm (located at the bottom section of the borehole wall). At each depth, 11 touch points were recorded, which is even beyond of what the British Standard [BS 7172, 1989] requires (which is 7 touch points).

The hole surface roughness was also measuredwith an interval of 8 to 16 holes to align with the implication of tool wear rate. The surface roughness profile was measured in parameters of Ra, Rz, and Rt. The measurement setup chosen was as follows: cut off value of 0.8mm, evaluation length of 4 to 8mm, and a Gaussian filter. Two measurement locations were set: (1) for the wall near the countersink, and (2) near the bottom wall. This method was chosen as it was reasonable to assume that the surface finish changes with borehole wall.

3. RESULTS AND DISCUSSION

Figure 2 illustrates the tool wear and aluminum built up edge (BUE)difference on the cutting edge of both tools.



(a) (b)

Figure 2 Digital optical magnified image (X10) of both tools cutting edge after drilling 338 holes :
(a) Tool 1 (b) Tool 2

As shown in Figure 2, BUE adhered on the cutting edge of the enhanced speed drilling was relatively thinner compared to conventional speed drilling. This evidence was also found by Trent [10] and Farid et al [2] which the latter stated that the formation of BUE can be attributed to the welding of a deformed chip to the chisel edge surface at low cutting speeds. However, it did not occur at high cutting speeds as there was insufficient time for the deformed chip to weld at the cutting edge. BUE height measurement at different tool life is reported in Figure 3

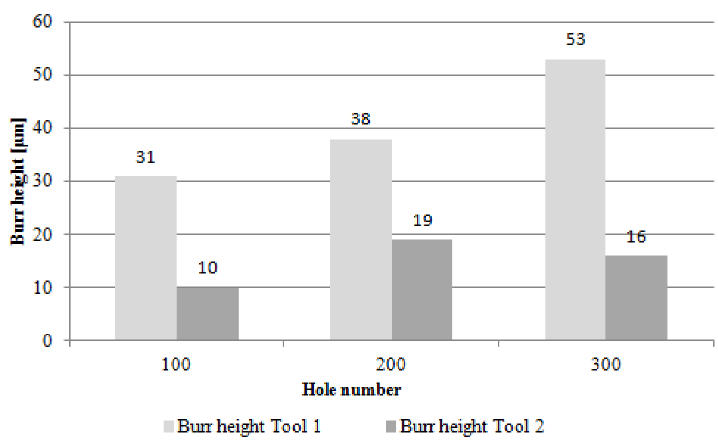


Figure 3 Built up edge (BUE) at different tool life stages (hole 15, 175, 338) on both tools

From Figure 3, it can be depicted that by drilling with an enhanced cutting speed, aluminum BUE grows at a slower rate. A research by Trent suggests that the disappearance of large built edge coincided with the appearance of cratering type of wear on the rake surface of the tool, but on a slow rate on mid-range speeds and worse above that[10]. Somehow, on this research the appearance of this crater wear was not yet to be detected. Overall, tool wear was difficult to observe and measure due to the dynamic shape of the cutting edge and the limited magnification of the optical microscope. Furthermore, upon drilling 338 holes, tool wear measurements of both tools does not show any discernable tool wear. Nevertheless, many authors suggested that abrasive flank wear does occur at almost all speed condition. This infers that it highly likely occurred within this experiment, yet at a low level of tool wear such that it was not measurable utilizing the chosen optical microscope[1],[10].

The measured temperature of drilling with a new tool and a worn tool at both drilling speeds, are presented in Figure . It presents the maximum drilling temperature measured at different depths between a new tool and worn tool, at both cutting speeds.

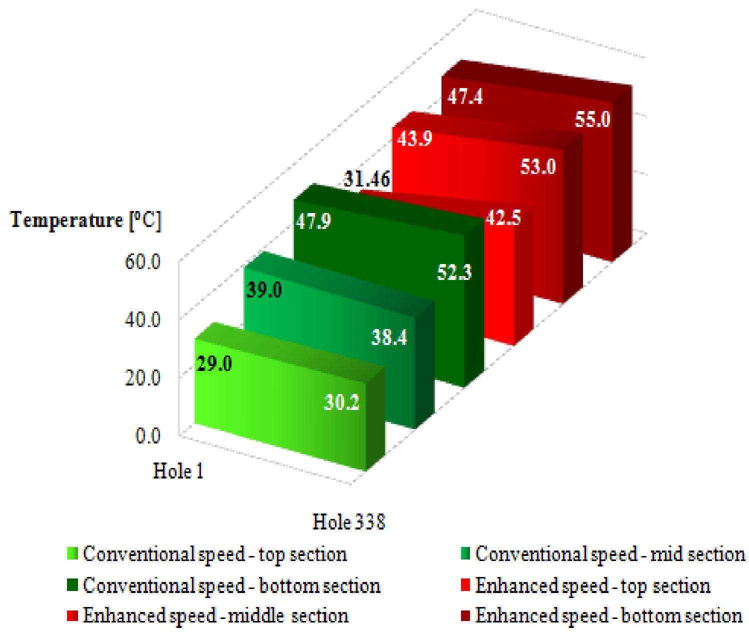


Figure 4 New tool and worn tool drilling temperature measured at both cutting speeds

From Figure 4 it can be observed that the temperature of the drilled hole generally increases as the drill tool cuts from the top towards the bottom section of the hole. As suggested by Danish, the heat continuously generates during cutting, but the cooling effect from the cutting fluid decreases as the drill tool cuts from the top to the bottom of the hole[15].As more holes were drilled and tool wear grows, it becomes apparent that the drilling temperature increases as a result of additional friction from the tool wear of both cutting tools thus generating more heat compared to drilling with a new tool.

It also appears from Figure 4that the enhanced-speed drilling produced a higher drilling temperature. This is mainly caused by the faster strain rate and also friction which occurred during enhanced-speed drilling, thus resulting in a more rapid heat flux generation on the shearing plane, thus increasing the drilling temperature.

The hole diameter accuracy of both drilling speeds is presented in Figure 5.

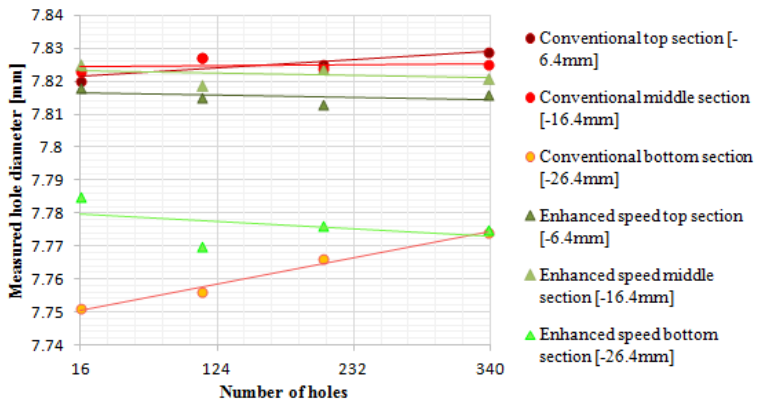


Figure 5 Measured diameter of the holes on different depths from both cutting speeds at different life stages (hole 16, 112, 208, and 338)

From Figure 5, it can be depicted that from both cutting speeds, the diameter at the top and middle section shows a larger diameter than at the bottom section. It can also be depicted that as more holes were drilled, at each depths, enhanced speed cutting tends to make smaller holes, shown by the declining slope, the opposite tendency of the conventional speed cutting. As the drilling commences and temperature rises at higher levels as the holes get deeper, the wall of the borehole at the bottom section retract farther than the middle and top section from the center drill as it expands. After the temperature returns to room temperature, all the aluminum particles than shrinks to its room temperature size thus resulting in a hole diameter smaller than the hole diameter when it was drilled.

Figure 6 shows a cutaway view of the 1st hole and last hole drilled of each cutting speed.

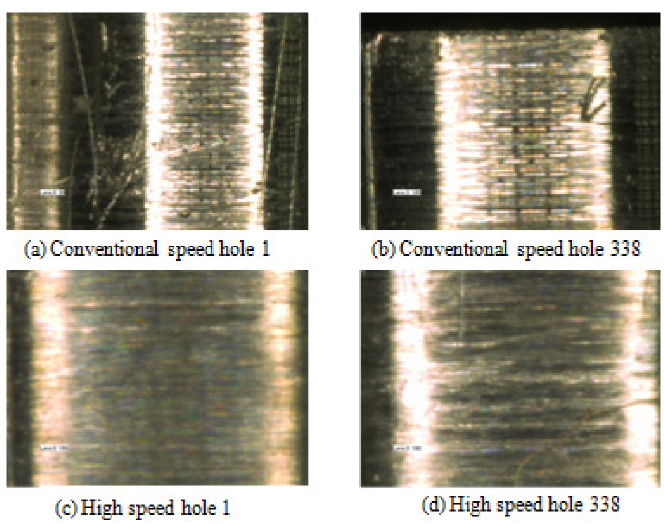


Figure 6 Cutaway view magnification drilling holes

It can be observed from Figure 6 (a) and (b), the holes drilled by conventional speed produced a rougher surface compared to enhanced speed drilling (c) and (d). The measured hole wall surface roughness, Ra between both drilling speeds are presented in Figure 7.

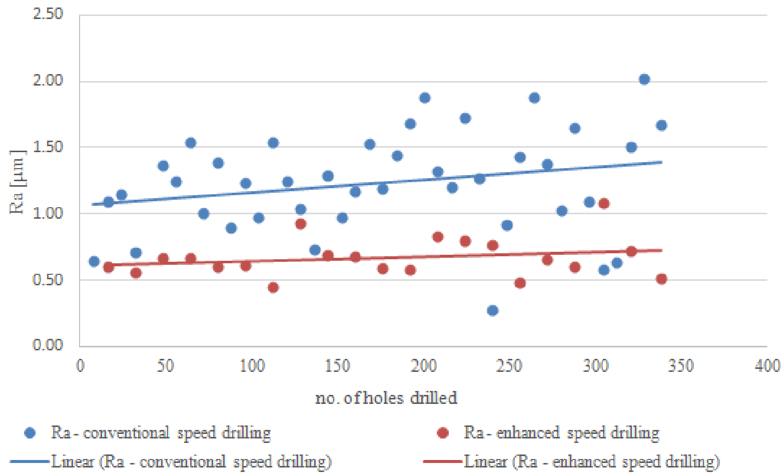


Figure 7 Surface roughness (Ra) after drilling 338 holes

It can be depicted from Figure 7that the average surface roughness Ra at enhanced speed drilling is smoother than conventional speed drilling. It is possible that the increase in temperature expands the holes wall and also increases the wall malleability, thus causes the cutting process to produce smoother hole walls. However, as more holes were drilled and malleability increases, the growth in tool wear and BUE and also movements of longer chips tends to cause scratches at the surface wall. As mentioned by Astakhov, in some cases, slow cutting speed have the effect of burnishing the hole, creating unwanted bright spots on the hole walls, and causing tool wear[11].

The exit hole quality between both drilling speeds were also observed and it shows that only three poor exit burrs were produced during conventional speed drilling while there were seven holes with crown and uniform burrs produced during enhanced-speed drilling. The other remaining holes have minimum burrs with only few microns height. Figure 8represents the exit burrs on conventional and enhanced speed drilling, respectively.

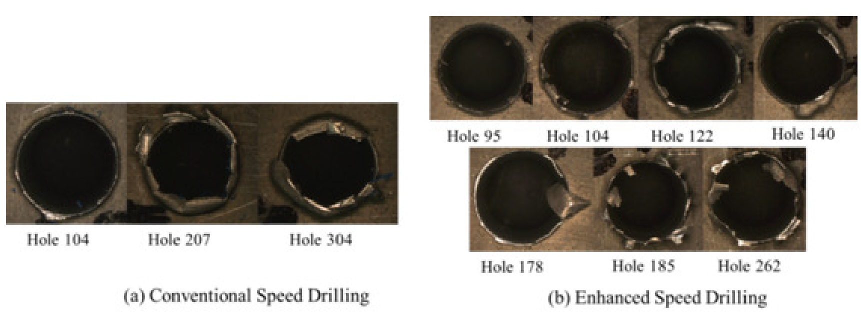


Figure 8 Exit burr formation on both work piece

It can be depicted from Figure 8(a) and (b), as the experiment reaches the last hole drilled, exit burr formation becomes worse. It refers to the increase in malleability of the work-piece, therefore, rather than cutting out the work-piece bottom surface as chips, it plastically deformed out as burrs[12,13].This phenomenon also explains the more frequent poor burrs produced on enhanced-speed drilling shown in Figure 8(b) due to higher elevated drilling temperature. This causes the burrs mostly shape as thinner crown burrs especially when more tool wear and BUE grows.

4. CONCLUSION

The drilling experiments were conducted on Aluminum Alloy AA7050 plates at both conventional and enhanced cutting speed utilizing two identical carbide drill tools. Analysis of the experiment result clarifies the difference in hole quality (borehole diameter, surface roughness, exit burrs) in respect with tool life, cutting speed and drilling temperature. Overall, enhanced speed cutting produced better diameter accuracy, better surface wall roughness with the downside of producing thin crown burrs on the hole exit. However, tool wear was undetected due to the limited optical microscope magnification, yeten hanced speed cutting showed a thinner built up edge height on the cutting edge compared to conventional cutting speed.

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Edo studied Mechanical Engineering at Institut Teknologi Bandung, Indonesia, obtaining the degree *Sarjana Teknik* in 2010. He then worked at a local special purpose machinery equipment maker and line integrator company appointed as head of engineering and operation documentation, working on manual and maintenance book of each projects and also on the director monthly sales review presentation. He was also involved on the quality system management project aimed at the workflow of the company, and later spent time on supervising the assembly of a 3-axis CNC machine. He gained MSc in advanced manufacturing technology and systems management from the University of Manchester in 2016, by conducting a research project with Dr. Robert Heinemann, entitled “Investigation of Hole Quality And Tool Wear in High-Speed Drilling of Al 7050” a project with AIRBUS. Since 2016, Edo is a lecturer at the Faculty of Engineering and Computer Science at Universitas Bakrie.

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