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Optimization of Drilling Cutting Parameter and Analysis of Chip Formation When Producing Hole for S50C Material

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Abstract: The geometry of the cutting tool and the cutting parameters strongly influence the shape and forming mechanism of the chip in the final drilling process. Therefore, the objective of this study is to optimize the cutting parameters of the drilling process in terms of cutting speed and feed rate by using surface roughness as the response. On the other hand, this study is to compare the performance for two types of cutting tool with different geometry design (DRS and EZ) in term of chip formation, chip thickness, and chip width. Chip formation, chip thickness and chip width were observed and measured by using tool maker microscope while surface roughness was measured by surface roughness tester. From the result, it shows a strong relationship between cutting parameters especially cutting speed and feed rate in the chip formation analysis. Besides, the increase of feed rate provides an opportunity to decrease the chip thickness and chip width for both different geometry design of cutting tool. Moreover, chip thickness and chip width is more affected by the feed rate. For surface roughness, DRS drilling bit it is most affected by cutting speed and for EZ drilling bit it is affected by feed rate. In conclusion, the best drill bit to be used in this experiment is the EZ type where it has standard flute with a curve design on it cutting lips.

Keywords: Drilling; Optimize; Cutting Parameter, Tool Geometries

1. Introduction

Machining is a term used to describe the various material removal processes in which the cutting tool extracts unnecessary material from the workpiece to create the desired form. The workpiece is usually cut from a larger piece of stock, which comes in a variety of standard shapes, such as flat sheets, solid sticks, hollow tubes and shaped blocks. To maintain stable machining, highly consideration must be assumed to the desired type of chip and chip controls to encourage its simple removal. This is for the reason that the chip formation and breaking aspect is very important in machining. In the chip formation process, even small changes also can cause issues regarding with surface finish, and workpiece accuracy especially in high speed machining. Strong surface quality is the idea that manufacturers should improve the functional and technical quality of the product (Balaji et al., 2016).

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Drilling is a method of cutting metal that requires the geometry of the cutting tool, the machine parameters, and the dimension of the workpiece needed. The geometry of cutting tools such as point angle and helix angle as well as machine parameters such as cutting speed, feed rate, and depth of cut needs to be set before the drilling process is carried out to produce a good work surface. The tool equipment affects the demented of the drilled hole, the tool wear, the surface quality, and the chip length and thus the chip morphology (Demir & Yakut, 2018). The cutting tool geometry is importance because it directly defines the direction of chip flow and the direction is important to control chip breakage and evacuation. Other than that, the cutting tool geometry will also affect productivity of machining, tool life, and quality of machining such as surface integrity (Davim, 2008).

If operating with slow cutting speed and feed rate, the process can be less efficient and take more time. If the cutting speed and feed rate operation is too fast, quick wear of the tool will result in poor surface roughness and reduced work piece dimensional accuracy. Therefore, it is important to optimizing the parameter of drilling process to use the most appropriate cutting speed and feed rate values because using optimal process parameters can produce good hole surface quality (Popan et al., 2017). Meanwhile, larger cutting depth will cause waste to materials and higher production costs.

2. Materials and Methods

2.1 Machining Parameter

The parameters are very important and need to be properly considered in the experiment. In this experiment the main parameters were used involving cutting speed, *Vc*, feed rate, *fr*, and cutting depth, DOC. Besides, the value of depth of cut was 40mm throughout the experiment. The combination of drilling parameter value/level such as the cutting speed and feed rate values that have been set in the experiment as shown in Table 1.

Table 1: Drilling combination

No. of Experiment	Drilling parameter	
	Cutting Speed (rpm)	Feed Rate (mm/min)
1	1300	230
2	2600	460
3	3900	690
4	1300	460
5	1300	690
6	2600	230
7	2600	690
8	3900	230
9	3900	460

2.2 CNC Milling Machine

The MAZAK Vertical Center Nexus 410A-II CNC milling machine (3 axes) is used in the drilling process as shown in Figure 1. This type of milling machine has many advantages as it can reduce production time during machining. Figure 2 showed the setup of the experiment.

2.3 Material Carbon Steel (S50C)

The material used in this experiment is carbon steel S50C. The characteristic of carbon steel (S50C) are good strength and impact properties, with good machinability and reasonable weldability in the as supplied condition.

2.4 Cutting Tool

Two type of cutting tool with different geometry design that used in this experiment were DRS and EZ drill bit. Both types of the drill bit have different type of flute and cutting lips design which affect to chip formation as well as surface roughness. Table 2 showed the cutting tool specification.

Table 2: Cutting Tool Specification

Specification	Drill type	
	DRS	EZ
Type of drill	Twist drill	Twist drill
Type of flute	Parabolic flute	Standard flute
Design of cutting lips	Straight	Curve
Drill diameter (mm)	8	8
Point angle (°)	140	140
Helix angle (°)	30	30

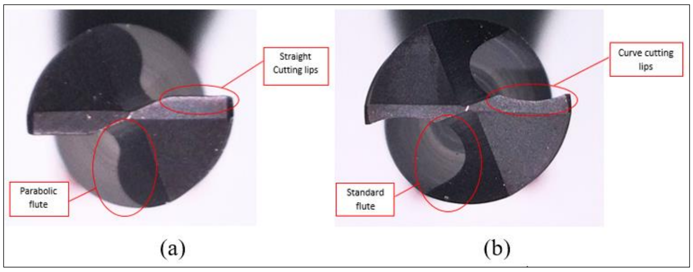


Figure 1: (a) DRS drill bit (b) EZ drill bit

2.5 Surface Roughness Measurement

The surface roughness for the resulting hole was measured using a Mitutoyo surface roughness tester. The surface roughness measurement was conducted according to the carbon steel S50C. The workpiece block will cut into half horizontally before measuring the surface roughness. Measurement will be done four times where two times measured at the top of the hole and another two times measured at the bottom of the hole.

2.6 Tool Maker Microscope

The microscope used to measure the chip thickness and width. The chip is placed on the workbench of the tool maker microscope, and at the same time the chip image is observed and measured by the magnifying glass.

2.6 Minitab statistical software

The Taguchi method is carried out using Minitab software version 2018 which allows the main objective which is to analyze the effectiveness of the combination of parameters and optimize the parameters. The method of using this software is also very simple and does not need to take long to learn how to use it. The response data that used for Taguchi method was surface roughness. Taguchi method the mean and the variance of the response from the experiment data are combined into a single performance measure known as the signal-to-noise (S/N) ratio (Basil et al., 2016).

3. Results and Discussion

The aim of this study is to optimize the drilling parameters in terms of cutting speed and feed rate to produce hole for carbon steel S50C. The objective need to be based on several features. The first is optimizing the cutting parameter in term of cutting speed and feed rate that used surface roughness on the hole S50C as response. Secondly, chip morphology where the chip formation, chips thickness and chip width of every experiment were analyzed.

3.1 Optimization Parameters of Cutting Tool with Response Surface Roughness Using Taguchi Method

The surface roughness of the workpiece was measured at four different locations which is two at the top of the hole and another two at the bottom of the hole for one hole using surface roughness tester. Table 3 shows the results of surface roughness when drilling carbon steel (S50C) with two type of cutting tool and different of cutting speed and feed rate.

Table 3: Overall Average of *Ra* value for DRS & EZ

Cutting speed (RPM)	Feed rate (Mm/min)	DRS Overall Average *Ra*	EZ Overall Average *Ra*
1300	230	1.358	1.242
	460	1.664	1.122
	690	3.944	0.821
2600	230	1.717	1.120
	460	1.400	1.038
	690	0.972	1.253
3900	230	1.255	1.294
	460	0.969	1.207
	690	1.410	1.045

The Taguchi method is carried out using Minitab 18 software. Taguchi method will be used in analyzing the resulting surface roughness on the hole. The lowest surface roughness value is definitely the best value because it produces a smoother surface rather than surfaces that have a higher roughness value. In Taguchi method, "the-smaller-the-better" concept is chosen to determine the best combination of cutting conditions and optimize cutting parameters in producing quality holes for both types of cutting tools. The-smaller-the-better concept means the S/N ratio that close to zero is the better.

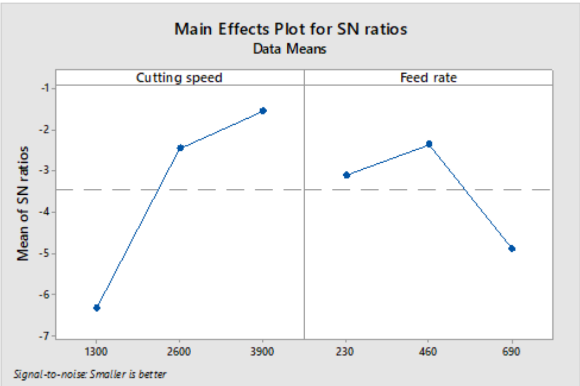


Figure 2: Main effect plot for S/N ratios of DRS drill bit

Table 4: Response Table for S/N Ratios for DRS drill bit

Level	Cutting speed	Feed rate
1	-6.333	-3.109

2	-2.457	-2.357
3	-1.561	-4.885
Delta	4.772	2.528
Rank	1	2

Figure 2 shows that when the cutting speed increases from 1300 rpm to 3900 rpm, the surface roughness decreases. According to the stated by (Cui et al., 2012), increasing the cutting speed attributed to decreases of surface roughness. It can also be observed that a better surface finish can be obtained at the highest cutting speed (3900 rpm) and medium feed rate (460 mm / min). Besides, the cutting speed is important which can lower the surface roughness value such as increasing the cutting speed.

Table 4 shows that the cutting speed is at rank number one factor affecting the surface roughness compared to the feed rate which is ranked at number two. It also shows that the S/N ratio value that closed to zero for both cutting speed and feed rate are -1.561 of 3900 rpm and -2.357 of 460 mm/min respectively. These results indicated that cutting speed was the highest contribution to minimum the surface roughness.

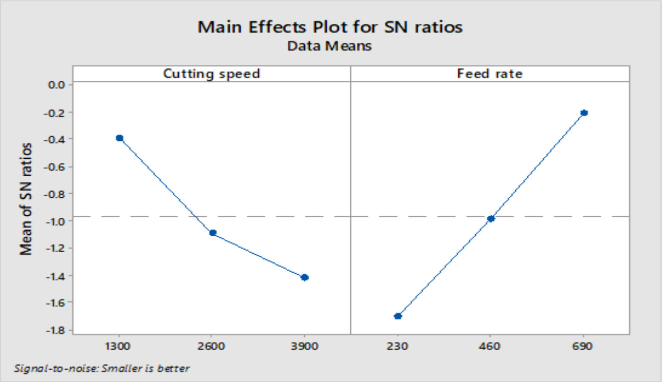


Figure 3: Main Effect Plot for S/N Ratios of EZ Drill Bit

Table 5: Response Table for S/N Ratio for EZ Drill Bit

Level	Cutting speed	Feed rate
1	-0.3897	-1.7018
2	-1.0891	-0.9860
3	-1.4184	-0.2094
Delta	1.0287	1.4924
Rank	2	1

Figure 3 determines that when the feed rate increased from 230 mm/min to 690 mm/min, the surface roughness was decreased. According to the study stated by Demir & Yakut (2018) the feed rate is a significant parameter, affecting the process quality and the surface roughness, more than the cutting speed in the drilling process. It is also can observed that better surface finish can be obtained at the lowest cutting speed (1300 rpm) and highest feed rate (690 mm/min). Besides, feed rate is most important for EZ drill bit which can decrease the value of surface roughness as increase the feed rate. Based on table 5, it shows that the feed rate is at rank one for the factor that affecting the surface roughness rather than the cutting speed which is ranked at number two. These results indicated that feed rate was the highest contribution to minimum the surface roughness for EZ drill bit.

3.2 Chip Formation

Figured 4 shows the stage of chip formation in drilling process that use two type of cutting tool which is DRS and EZ cutting tool. From stage 1 to stage 3 is the acceptable chip in drilling where it can produce good surface roughness on material S50C while chip jamming will produce uneven surface on the hole. In stage 6 is undesired chip formation which will definitely affect the surface of the hole even more severely compare to folded ribbon chip. In this experiment, chip jamming is produced when interrupted sound is produced same as stated (Sandvik Coromant, 2014) a consistent sound means that chip evacuation is good, but an interrupted sound indicates chip jamming. Other reason the chip along the cutting edge is not generated uniformly is because to the special geometry of drills (Zhu et al., 2018). During deep hole drilling, chips usually do not maintain a uniform shape as drilling depth increases. The initial chip always has a spiral shape (Ke et al., 2005).

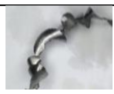
 Stage 1	 Stage 2	 Stage 3	 Stage 4	 Stage 5	 Stage 6
Initial conical chip	Steady-state conical chip	Transition between conical chip and irregular conical chip	Irregular conical chip	Folded ribbon or chip jamming	Undesired chip formation or chip jamming

Figure 4: Stage of Chip Formation

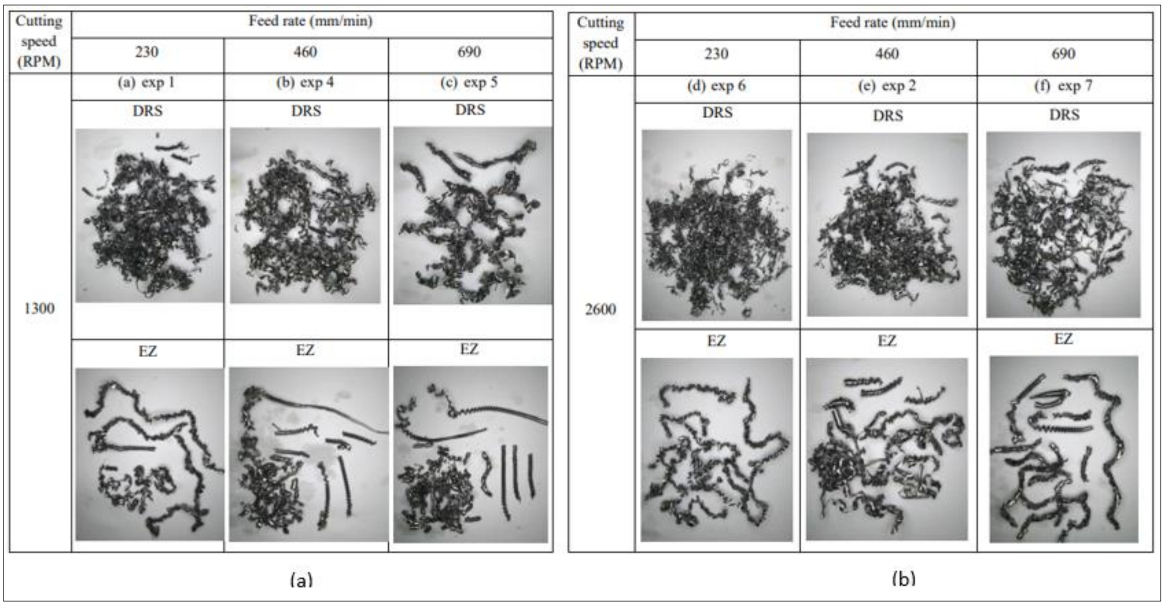


Figure 5: Chip Formation for DRS & EZ Drill at Cutting Speed 1300rpm and 2600rpm

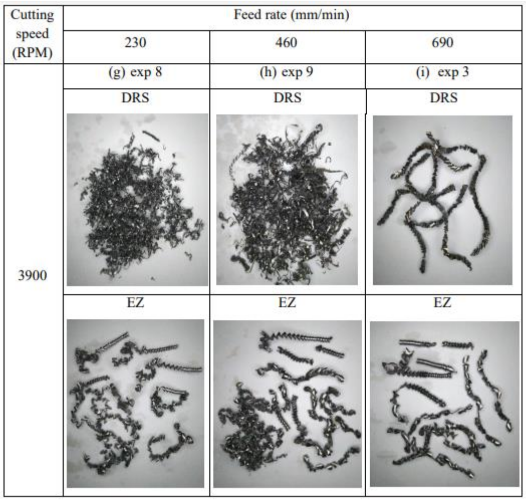


Figure 6: chip formation for DRS & EZ drill for Cutting Speed 3900rpm

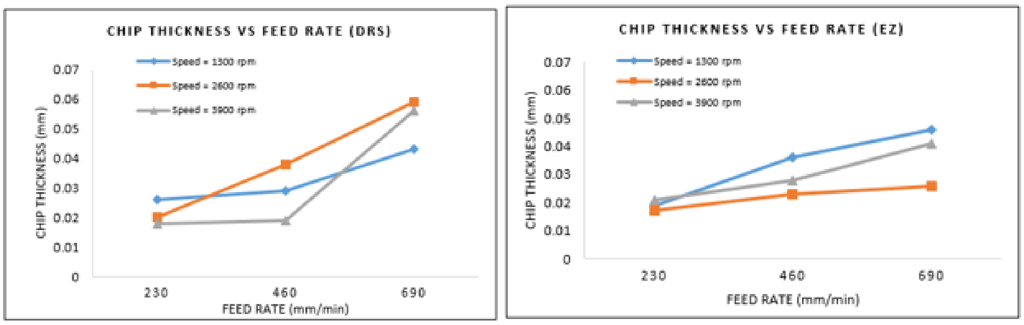
Based on Figure 5(a), for the experiment 1, the DRS and EZ drill bit produced the same chip formation which is conical chip, irregular conical chip, and folded ribbon chip that reached at stage 5. The chip produced by DRS drill bit also smaller than chip that produced by EZ drill bit. After that, in experiment 4, the DRS drill bit produced conical chip, irregular conical chip, and folded ribbon chip (stage 5). While, EZ drill bit produced conical chip and irregular conical chip where only reached at stage 4 only which can give good surface roughness. Next, in experiment 5, the folded ribbon and undesired chip were formed for DRS drill bit where it was at stage 6 of the chip formation which can cause poor surface finish on the workpiece. While EZ drill bit were produced conical chip and irregular conical chip where only reached at stage 4 that can give better surface roughness. The other different is the size of chip that produced by DRS drill bit larger than chip that produced by EZ drill bit.

Figure 5(b) shows the resulting chip formation with combination of medium cutting speed (2600 rpm) and three different levels of feed rate. In experiment 6, DRS drill bit were produced short conical chip and irregular conical chip (stage 4). While EZ drill bit produced only irregular conical chip and folded ribbon chip (stage 5). On the other hand, chip’s size that produced by DRS drill bit is smaller than size of chip that produced by EZ drill bit. Meanwhile, in experiment 2, DRS and EZ drill bit were formed the same type of chip formation which are conical chip and irregular conical chip that reached at stage 4 only that can give better surface roughness but both drill bits produced different size of the chip. Eventually, in experiment 7, DRS drill bit were produce better chip formation which is short conical chip and irregular conical chip (stage 4) compared to EZ drill bit that produced conical chip, irregular conical chip, folded ribbon chip and undesired chip that reached at stage 6 which can cause poor surface roughness.

Figure 6 indicates the resulting chip formation with combination of high cutting speed (3900 rpm) and three different levels of feed rate. It shows conical chip and irregular conical chip were formed in experiment 8 for DRS and EZ drill bit that reached only at stage 4 and give better surface roughness to the hole that produced. Besides, in experiment 9, DRS and EZ drill bit also produced the same chip formation which are conical chip and irregular conical chip that reached at acceptable level (stage 4). However, chip’s size that produced by EZ drill bit is larger. Other than that, in experiment 3, folded ribbon chip and undesired chip was form for DRS drill bit where it is located at stage 6 of chip formation which can cause poor surface finish, while EZ drill bit only produced conical chip and irregular chip that reached at stage 4 that can give better surface roughness.

In addition, resulting chips in terms of shape and size is different for every experiment because the interaction of the chips with the drill flute and hole wall results in further deformation of the chip (Mathew, 2016).

3.3 Effect of cutting parameter on chip thickness for DRS and EZ drill bit



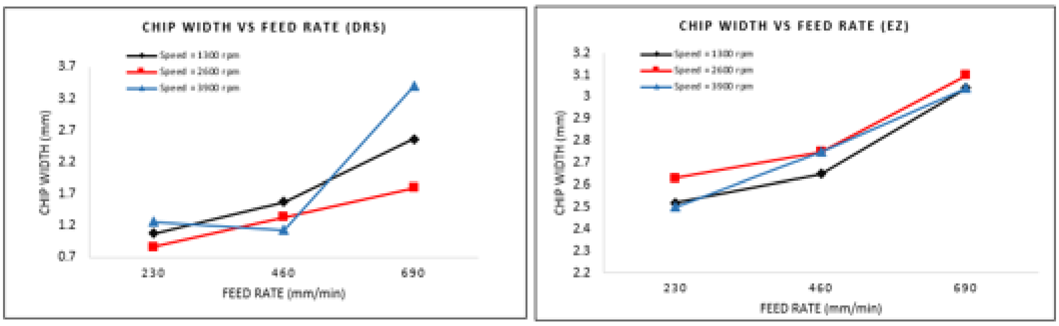
(a) (b)

Figure 7: Graph chip thickness vs feed rate for (a)DRS and (b)EZ drill bit

Based on Figure 7(a), for DRS drill bit, the average chip thickness produced by the drilling process using DRS drill bit is increased along with an increase in feed rate on each combination of the same cutting speed with the different feed rate. In this experiment, maximum chip thickness values were obtained at feed rate 690 mm/min and cutting speed 2600 rpm. It can be said that the feed rate greatly affects the thickness of the chip. While the cutting speed show an insignificant effect because the graph plotted was fluctuating.

The graph on Figure 7(b) shows average chip thickness against feed rate obtained. It is observed that feed rate factor greatly affects the increase in the resulting average of chip thickness on EZ drill bit because the average of chip thickness significantly increased with rise in the feed rate. In this experiment, maximum average of chip thickness value was obtained at feed rate 690 mm/min and cutting speed 1300 rpm. It means that, feed rate is the important factor that affect the average of chip thickness for EZ drill. While the cutting speed is less of a factor that effect to the chip thickness on EZ drill bit also because the uneven plotted graph.

3.4 Effect of cutting parameter on chip width for DRS and EZ drill bit



(a) (b)

Figure 8: Graph chip width vs feed rate for (a)DRS and (b)EZ drill bit

From the Figure 8(a), it shows that the average chip width produced by the DRS drill bit is increased along with an increase in feed rate of the same cutting speed which is at 1300 rpm and 2600 rpm. Meanwhile, at the cutting speed 3900 rpm, the average chip width produced against 3 levels of feed rate which is 230 mm/min, 460 mm/min and 690 mm/min are fluctuating. While the cutting speed show an insignificant effect because the graph plotted was more fluctuating.

Based on the Figure 8(b), the graph shows average chip width against feed rate from the experiment that uses EZ drill bit at 3 levels of cutting speed and feed rate respectively. From the graph, it is observed that the average chip width produced by the drilling process using EZ drill bit is increased along with an increase in feed rate on each combination of the same cutting speed with the different feed rate. Eventually, cutting speed is less of a factor that effect to the chip width because it shows the chip width increased from low cutting speed (1300rpm) to medium cutting speed (2600rpm) while decreased from medium cutting speed to high cutting speed(3900rpm) for the same feed rate.

3.5 Discussions

Cutting speed greatly affects the hole surface roughness produced by using DRS drill which is when the cutting speed increases, the surface roughness of the hole produced decreases. According to (Sultan et al., 2015), the decrease in surface roughness with increasing cutting speed can be attributed to the reduction of built-up edge (BUE) during the chip formation process and it can cause better surface finish. Other than that, according to (Marigoudar & Sadashivappa, 2012), the presence of built-up edge (BUE) will cause an increase in friction and produce a high cutting force. So, for DRS drill, it requires a high cutting speed of 3900 rpm to reduce the tendency to form unsteady built-up edge (BUE) formation.

EZ drill does not require high cutting speed because the curved design on the cutting lip can make the process of cutting and removing chips smoother and in turn can prevent the formation of built-up edge (BUE). This is because the motion for the curve and straight cutting lips to remove the chip is different. Other than that, the cutting force of the curved lips is slightly smaller than those of the straight curved drills (Matsumura & Leopold, 2010). In addition, if the cutting force decrease, the surface roughness also decrease (Hoang et al., 2019). Therefore, high feed rate value (690 mm/min) is suitable for this type of drill bit to obtain a lower surface roughness value.

Other than that, for the experiment that using DRS drill bit, the chip formation produced in experiment 9 was the better chip formation that only reaches stage 4 in the stage of chip formation and has the lowest surface roughness value which is 0.969µm. However, the value of chip thickness in experiment 9 was 0.019 mm where it is the lowest value. For the experiment that using EZ drill bit, the chip formation that produced in experiment 5 was the better chip formation that also reach at stage 4 in stage of chip formation. While, for the chip thickness value that produced in experiment 5 is the highest which is 0.046 mm and produced the medium value of chip width which is 3.04 mm. It also can be said that the decrease of feed rate provides an opportunity to decrease the chip thickness and chip width for DRS and EZ drill bit.

It shows that the EZ drill bit produced a more consistent surface roughness which is in the range of 0.821 um to 1.294 um. Meanwhile, for the DRS drill bit, it produced the surface roughness value with a larger range of 0.972 um to 3.944. It is due to the special geometry design on the drill bit. According to (Matsumura & Leopold, 2010), cutting lips with a small curved design is effective in reducing the thrust and can control the flow of the chip, as well as the designed lip cutter also can flow the chip upwards by preventing the chip from clogging in a stable process.

4. Conclusion

In conclusion, to produce better surface roughness on the hole, the drill bit to be used in drilling the S50C is EZ drill with curve cutting lips and standard flute type. This is due to the EZ drill bit produced the lowest value of hole surface roughness which is 0.821 µm. Besides, it also can produce more consistent surface roughness with different combination of cutting speed and feed rate.

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