Chip Formation and Shear Plane Angle Analysis on Carbon Steel Drilling using Solid Carbide Tools

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Abstract: The analysis of the chip formation and shear plane angle from the drilling process are conducted as a mean to determine the best drill bit used. Both aspects that influenced by the drill bit will define the machinability and quality of the machining process. The aim of this experiment is to determine which is the best drill bit to use. There are nine types of drill bit used in this experiment. All of the drills used are made of the solid carbide. The chips are obtained from the drilling conducted by HPMT Industries Sdn Bhd. There are several types of chips from the experiment, such as continuous, discontinuous and segmented chip. It is found that the chip's thickness and the helix angle of the drill bit affect the value of the shear plane angle created. Since all drill bits are made of the same material, the helix angle of the drill bit become the main factor of choosing the best drill bit because of the relationship between it influenced the shear plane angle value.

1 INTRODUCTION

One of the workpiece that is frequently and generally used in the machining process is steel. There are several types of steel used in the machining process such as stainless steel, carbon steel and others. Each type of steel has a different nature. Stainless steel is the most common type of steel used in the manufacturing industry. For example, corrosion resistant properties of stainless steel is due to a chromium content of 10-12 percent of the total weight of stainless steel (Kalpakjian and Schmid, 2006). Then there is also carbon steel which is also often used in industry because of its low cost and ease of manufacture (Smith and Hashemi, 2006).

One of the type of machining process which is often used for steel is drilling process. Drilling process is the process by which drill bit will result in a hole in the workpiece through direct contact between the tool and the workpiece surface. Drilling process is one of the most important machining processes in the automotive and aircraft industries. (El-Sonbaty et al., 2004) states that the industries required more than 100,000 holes for small aircraft engines, mostly used as a fastener. There are several forms of chips that could resulted from the drilling process (Sharman et al., 2008). For example, the long continuous chips are bad shape because chips will stick to the surface of the tool and affect the performance of the tool while performing the drilling process (Feng et al., 2005). Long chips also make the chip evacuation become more difficult and cause the drill to require more power, which would increase the risk of broken drill (Batzer et al., 1998). For this reason, the form and evacuation process of the chips have important roles.

Chips will have direct contact with the flutes on the twist drill during the drilling process. The geometry of the tool used will have an impact on the process of moving chips (Abrao et al., 2008). Because of that, the shape that commonly found has curls form, which is according to the flute's shape. (Bakkal et al., 2005) in experiments on the chip's morphology of drilling metal glass found that there are six forms of chips such as powder, short ribbon, long ribbon, long spiral, long twisted ribbon and fan shape.

Movement of the chips on the flutes will cause bending moments which can lead to chip fracture. (Sakaurai et al., 1998) states that the chip will be broken when the friction torque between the hole wall and chip's surface is beyond the chip's torque. The size of the chip will have impact on the surface roughness, which will produce rougher surface (Batzer et al., 1998). The performance of a tool can be determined by the shape of the resulting chips.

Therefore, apart from the chip removal process, the shape and length of chips resulted from the drilling process should be reviewed in order to accomplish better performance of the drilling process. In

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addition to differences in material and machining parameters on the tool used, the difference in the shape or geometry of the tool will affect the shape of the resulted chips (Wan and Tang, 2011). Geometric differences such as rake angle or helix angle and the point angle will affect the shape, size and length of the chips. Point angle, helix angle and size of flutes on the tool will affect the movement of chips (Feng et al., 2005).

So in this experiment will be analyzed on the fragments resulting from each type of device used. Each tool has a different geometry and analysis on the relationship between the different tool geometry and shape of the pieces will also be done. Then the relationship between the rake angle of the tool with the resulting shear plane angle will also be reviewed.

Figure 1 shows the geometry of the typical drill bit used in machining.

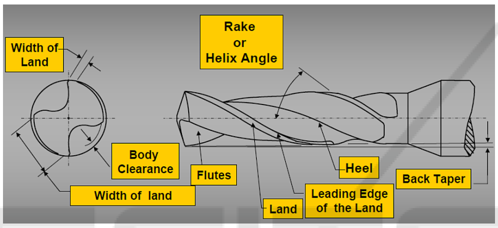

Figure 1: Drill Bit Geometry

2 EQUIPMENT

The workpiece used is carbon steel S45C. CNC machine is used for the drilling process. The diameter of all cutting tool used is 8 mm. All of them are not using coolant. There 9 drill bits, each has different helix angle value. Figure 2 shows the holes produced from the drilling process. From the process, there are 600 holes produced by using each cutting tools. Then figure 3 show the CNC Drilling Machine Makino S-33 that used in the drilling process.

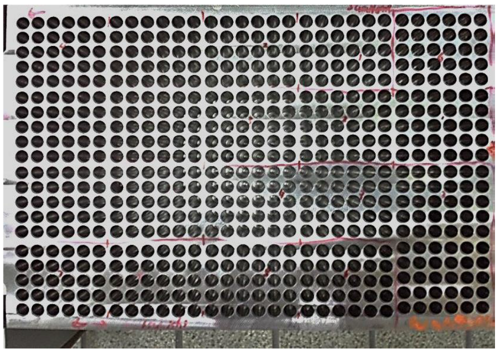

Figure 2: Carbon Steel S45C

Figure 3: Makino S-33 CNC Machine

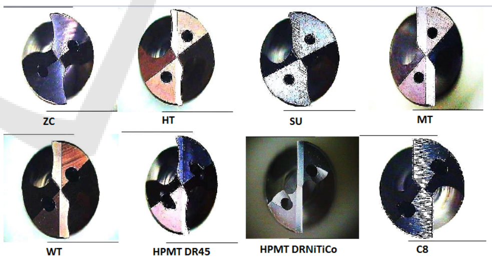

Figure 4: Drill Bits Used In The Drilling Process

3 METHODOLOGY

Every drill bit will drill 600 holes with same machining parameters, shown in table 1. Then the chips are taken randomly between the drilling process. the chip's thickness measured using vernier calliper. Thus, using the thickness ratio and helix angle value, the shear plane angle value can be found. These formulas are used for the calculation.

$$r = \frac{to}{tr} \tag{1}$$

$$\tan\Phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \tag{2}$$

Table 1: Machining Parameters Used

Cutting speed	Feed rate	Depth of cut
140 m/min	0.16 mm/rev	42 mm

4 RESULTS AND DISCUSSION

4.1 Chip Formation

From the chips sample, there are several forms of chip resulted from each type of cutting tools. Long helical continuous chip is always resulted in the drilling process. There are also discontinuous and segmented chip resulted. But there are only two cutting tools resulting segmented chips. Beside the shape, the length and thickness of the chips are also measured. The length of the chips are between 3 to 6 cm. Figure 5 below shows the sample of the chips.

Figure 5: Type of Chips Resulted From The Drilling Process

There are several types shapes of the chips resulted. With continuous being the dominant one, while some discontinuous and segmented are also recovered. There are no real significant difference in the shape due to the similarity value of the rake angle.

For the thickness value however, the differences between all the chips resulted from each cutting tools are quite similar. This is due to the similarity of the feed rate used in the drilling process. Table 2 show the value from the maximum length and thickness measurement of the resulted chips.

Chips from cutting tool C8 has the least maximum length of all the chips. As for he longest is from the cutting tool WT. Cutting tool ZC produce longest chips at 4.5 mm, and this cutting tool is the cutting tool that produce the most many long continuous helical chips. Long continuous chips also resulted from the use of all the cutting tools. But only ZC produce it as the most dominant chip's form. For the segmented chips, there are two cutting tools produced it, they are HT and MT. Using MT, there is also produced long continous string chips. As for the cause of this occurence, is likely due to the high cutting speed and influenced by the wear condition of the cutting tools.

From table 2, it can also show the value of the chip thickness. The small difference might happened due to the similar use of machining parameter,, especially feed rate that affect the chip thickness. There is no change in the parameter, which is making unclear to compare the chip thickness resulted from each cutting tools. Thus, the similarities between the values are obtained.

4.2 Surface Integrity of the Chip

Observation of the surface of the resulting chips were also conducted. The both of the chip surface was observed using an optical microscope. Of all the pieces, it is found that many chips with good machined surface (outside) or good quality. However, there is also the outer surface of chips having a surface shape is not good, as there is friction and cracked. The condition of the chip surface in contact with the workpiece has a resemblance to each other. There are traces of the strain acting on the surface of the chip, which occurred during the drilling process. The traces are resulted by the cutting tools.

From observation, it can be seen that the shape of the surface of the chips of each tool has a shape similar or even identical. Due to the dominant circular chip, it is difficult to observe the inner part of the chip. To do the observation of this part, the discontinuous chip type is observed so the inner surface can be observed. From the figure below, it is shown that the chips surface from HPMT DRNiTiCo has poor condition than the others. It can occured due to the cutting tools became dull (due to the wear).

4.3 Shear Plane Angle Analysis

Feed rate is used as the replacement for the t_o.There is a relationship between shear plane angle and rake angle. Because rake angle will define the sharpness of the cutting tool. Rake angle will affect the shear plane angle resulted. For drilling process, the rake angle is replace by the helix angle. Because helix angle (on flute) is the part that directy cut or touch with

Table 2: Chip's Length And Thickness Measurement

No	Drill Bit	Max Length (cm)	Thickness (mm)			
			1	2	3	Average
1	ZC	4.5	0.23	0.25	0.25	0.24
2	HT	4	0.29	0.24	0.23	0.25
3	SU	4.2	0.21	0.24	0.25	0.23
4	MT	4.4	0.26	0.2	0.21	0.22
5	WT	6	0.27	0.31	0.29	0.29
6	HPMT DR45	3.8	0.24	0.26	0.23	0.24
7	HPMT DRNiTiCo	3.5	0.31	0.29	0.25	0.28
8	C4	4.5	0.24	0.27	0.26	0.26
9	C8	3	0.21	0.22	0.25	0.23

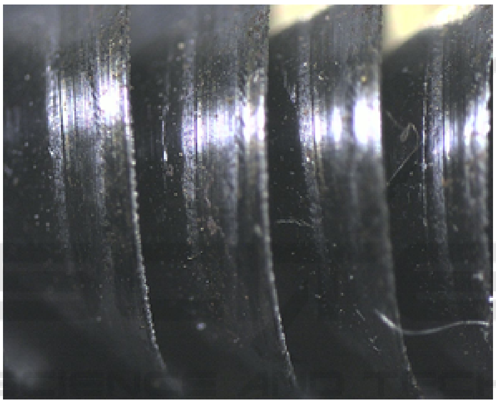

Figure 6: Chips of Drill Bit C8

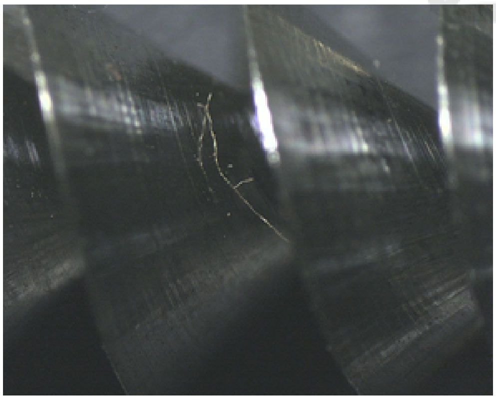

Figure 7: Chips of MT

the workpiece's surface and resulting the chip. The chip also flow through this part. So in this case, helix angle is related to the shear plane angle.Table 3 shows the rake angle and shear plane value.

From the table 3, it is known that the least thickness will cause the shear plane angle to increase. That

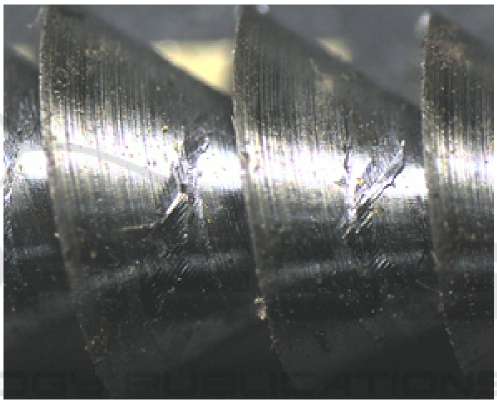

Figure 8: Chips of HPMT DRNiTiCo

shows the relationship between thickness and shear plane angle. Beside that, rake angle also influence the shear plane angle. It is seen that the smaller rake angle tend to produce smaller shear plane angle, except for C4 and C8. The value of the shear angle also will decreased if the rake angle is too large, such as WT show. This means that the rake angle value should be optimized to get the optimum value of the shear plane angle.

The chip thickness has more clear relationship with the shear angle. The smaller thickness will resulting the bigger shear plane angle. As figure 6,7 and 8 shows that the optimum value of the shear plane is around rake angle with 30°.

5 CONCLUSION

From the measurement and observation of the chip, it is concluded that there are several type of chip

Table 3: Shear Plane Angle Value of Every Drill Bit

No	Drill Type	Chip Thickness (tc)(mm)	Cutting Ratio	Helix / Rake Angle	Shear Plane Angle
1	ZCC	0.24	0.67	30.21	41.14
2	Hitachi (HT)	0.25	0.64	28.67	39.02
3	Sumitomo (SU)	0.23	0.7	30.16	43.03
4	Mitsubishi (MT)	0.22	0.73	30.69	45.02
5	Walter Titex (WT)	0.29	0.55	33.17	33.37
6	HPMT DR459670800	0.24	0.67	30.22	41.14
7	HPMT DRNiTiCoD08800	0.28	0.57	30.16	34.63
8	Coromant 460 (C4)	0.26	0.62	26.24	37.46
9	Coromant 860 (C8)	0.23	0.7	26.41	42.32

resulted such as continuous, discontinuous and segmented chip. Continuous is the most dominant chip of all, since it appeared on each tool. The segmented only appeared on HT and MT, and could occured due to the tool wear and randomness of the chip collected from the drilling process.

Shear plane angle is calculated and shows that it has strong and clear relationship with chip thickness value. As for the rake angle, it shows that the optimum value of rake angle must be specified if want to increase the shear plane angle. Meaning also to reduce the chip thickness to accomodate better chip evacuation during drilling process.

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