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Characterization of tool wear in friction drilling

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KEYWORD

Friction drilling
Tool wear
Chipless hole-making
Tungsten carbide

ABSTRACT

Friction drilling is a non-traditional hole-making process, where the rotating conical tool between the thin workpiece produces a heat due to penetration to soften the workpiece and form a hole. It creates a bushing without generates the chip. Tool wear in friction drilling is crucial because it affects the tolerances that are achievable. In this study, the tool wear characteristics of friction drilling on low carbon steel were experimentally investigated using tungsten carbide tool. Tool wear characteristics were quantified by measuring the changes in tool shape and weight reduction. The energy dispersive spectrometry was utilized to analyze the element containing on the tool surface, and the observation of wear was made using optical microscope and scanning electron microscope. The results indicated that the conical tungsten carbide tool is durable and can be used up to 1000 holes. The changes of tool shape and weight reduction were concentrated at the tool center and conical regions. It confirmed that the abrasive wear revealed at the same regions with circular grooves. The adhesive wear was observed at the tool center and conical regions, and oxidation wear was identified with a dark burned appearance at the tool surface.

1.0 INTRODUCTION

Friction drilling is a new progressive hole-making process that utilize the heat where is generated from frictional rotating conical tool and workpiece in initial penetration to soften thin-walled workpiece. It forms a hole and bushing without generating chip. Therefore, the friction drilling has potential of developing high efficiency, better surface quality and a green machining

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process without environmental impact (Miller et al., 2006a). Figure 1 indicates a schematic illustration of the friction drilling steps process and it consists of five stages. In initial stage, the center region of tool approaches and contacts to the workpiece. The friction thrust force by the tool produces a heat and softens the workpiece in the second stage. Subsequently, in third stage the workpiece changes to super-plastic stage and the tool push downward soften material by its conical region. In fourth stage, the tool continues to penetrate the workpiece completely by cylindrical region and also extruded forming a bushing on the workpiece. The shoulder region of tool pushes the aside material to form a boss. In final stage, the tool retracts and leaves with the hole and bushing. The thickness of the bush is observed two times of the workpiece thickness and no required cutting fluid for friction drilling process (Krishna et al., 2010).

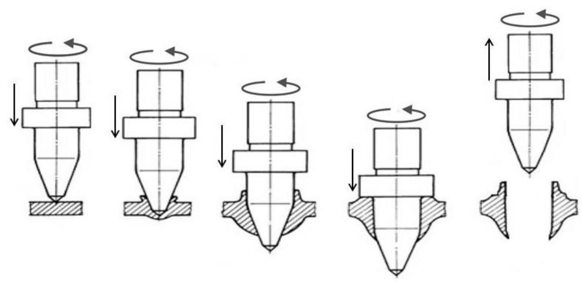

Figure 1: Schematic illustration of the friction drilling steps process (Krishna et al., 2010).

The wear of cutting tool can cause the disadvantages such as decreased tool life, inaccurate dimension, adversely affects the surface finish of the workpiece and high production cost (Gao and Xu, 2005; Chen and Li, 2007). The carrying on the machining process with a worn tool can increase the friction between tool and the workpiece and also increase the power consumption (Ambhore et al., 2015). Furthermore, late replacement of worn tool also may cause unpredictable machine breakdown at any time (Yumak and Ertunc, 2006). Tool wear in friction drilling also is a crucial factor that may affect the characteristics and tolerances on the desired hole diameter. It is in produce by the high temperature and forces generated in the where the tool nearly penetrates the workpiece, the stress is high inside the hole and causes material compression and required highest thrusts force to penetrate the workpiece process (Dehghan et al., 2017). Thereby, tool wear induces the increasing cutting force; the increased cutting force could accelerate the tool wear (Wang et al., 2016). Meanwhile, the excessive heat generated in the cutting zone results in high-energy concentration at the workpiece surface (Sharma and Sidhu, 2014).

Miller et al. (2006b) have conducted experimental study to measure the thrust force, torque, and temperature in friction drilling. The study on tool wear in friction drilling was characterized only by Miller et al. (2007) on low carbon steel with tungsten carbide tools. In conventional twist drilling process, the basic mechanisms of tool wear are abrasive, adhesive and oxidation wears, and types of wear such as flank, crater and central wears are produced at the tool tip (Dolinšek and Kopač 2006). The abrasive wear on twist drill tool of tungsten carbide is mainly caused to the presence of hard particles and segregated carbides within the workpiece material (Meena and El Mansori, 2013). Adhesive and oxidation wear mechanism was observed resulting in the formation of crater wear at the outer corner of the drill tool (Davim et al., 2006). Therefore, it has similar wear mechanism between friction drilling and conventional drilling method with influence of temperature due to high thrust force during drilling process.

In this study, the characterization of tool wear in friction drilling process on low carbon steel AISI 1018 was experimentally investigated using tungsten carbide (WC) drilling tool. The tool wear was quantified by measuring the changes in tool shape and weight reduction. In addition, the affected of worn tool on desired hole diameter was conducted by measuring the diameter of drilled hole. The evaluation of worn tool was carried out to characterize worn tool surface features and to analyze the surface chemistry of the worn tool tip.

2.0 MATERIALS AND METHODS

The friction drilling tool study was conducted by using a three-axis computer numerical controlled (CNC) milling machine. The experimental setup is shown in Figure 2. The workpieces were clamped using a vice and block gauges supported the both ends of the workpiece to prevent bended during tool penetration. The low carbon steel AISI 1018 was used as a workpiece. It is widely used for fixtures, mounting plates and spacers. The workpiece was square tubing with wall thickness of 1.5 mm, width of 25.4 mm, and average length of 190 mm. Square tubing was ideal for drilling many holes because it has four sides can be drilled. In this study, tungsten carbide WC was used as drilling tool. The dimension of the drilling tool is shown in Figure 3. Chemical composition of AISI 1018 and WC is shown in Table 1 and Table 2, respectively.

Figure 2: Experimental setup.

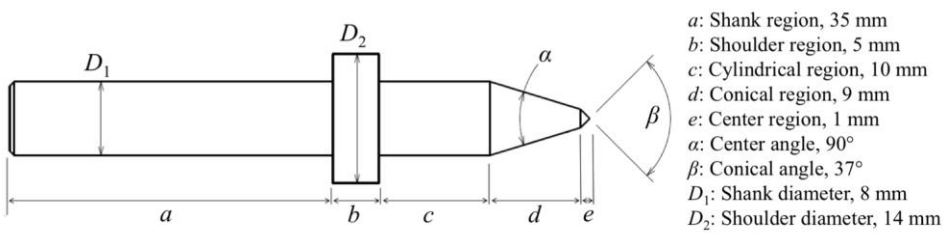

Figure 3: Dimension of the drilling tool.

Table 1: Chemical composition of AISI 1018 (wt.%).

C	Si	Mn	P	S	Fe
0.14-0.2	0.07-0.6	0.6-0.9	0.04	0.05	Balance

Table 2: Chemical composition of tungsten carbide (wt.%).

C	Ni	Cr	Fe	W
4.8-5.6	8.5-11.5	4.4-5.6	<0.3	Balance

The spindle speed and feed rate are set at 2800 rpm and 254 mm/min, respectively. These are common process parameters for friction drilling on low-carbon steel (Miller et al., 2005; 2006b; 2007). After each drilled hole, the drilling tool was automatically moved 12 mm to new position for next hole. Approximately 30-35 holes could be drilled on each side of the square tube. Each hole took about 3 seconds to drill, which allows the heat dissipation from the drilling tool and the time between each hole was set to 8 seconds due to the high temperature in the process. The tool profile and diameter of drilled hole was measured using profile projector. While, the weight of drilling tool was measured using precision weighing scale. The energy dispersive spectrometry was utilized to analyze the element containing on the tool surface, and the observation of wear was made using optical microscope and scanning electron microscope. A Kistler piezoelectric dynamometer was used to measure the axial thrust force during the friction drilling process.

3.0 RESULTS AND DISCUSSION

Figure 4 indicates the tool profile that measured at seven locations, marked as A to G. Points A and B are represent the radial wear at cylindrical region, which form the holes and very important to obtain the accurate hole dimension. While, tool wear at conical region is measured at point D and E. Point C and F are the tool wear at the intersection of cylindrical-conical regions and conical-center regions, respectively. The point G is the axial wear at the tool tip. It can be observed that the tool profile gradually tapered with number of run, and points of A, B, and C indicated very slight wear occur that is about 0.4-0.7%. The wear may negligible at cylindrical region. It confirmed that the cylindrical region is undergoing very little friction because the conical region has softened the material and formed the hole in third stage of friction drilling process. At conical region (Point D and E), the friction is more occurred as it makes thrust force on workpieces and form bushings. Starting from hole number 200, it can be seen a clear trend showing decreasing tool dimensions. At point E, after drilling 200 holes, it shows the dimension increases from 2.038mm to 2.055mm, this shows an evidence of the material adhesion from the workpiece to the tool. The point F shows a significant decrease indicating the occurrence of frequent friction occurred at this point. The wear at point G is the largest and increases rapidly. After drilling 600 holes, it indicates the center point has been lost due to the friction that occurs on it.

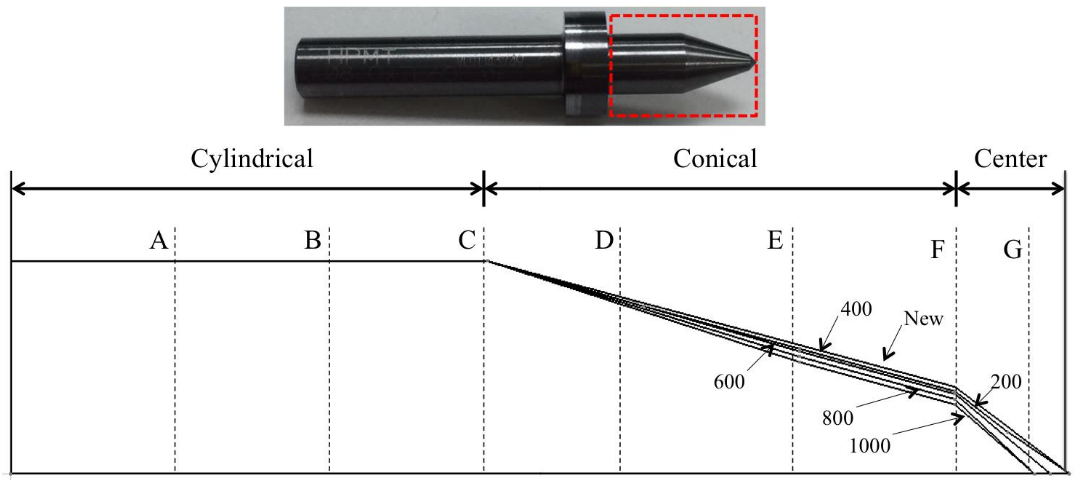

Figure 4: Tool profile measured at seven locations.

Tool wear is associated with the reduction of tool weight. Figure 5 shows the weight lost until drilling 1000 holes. It shows the decrease trend of tool weight. After drilling 200 holes, the tool weight started to reduce with 0.6% compared from new tool. It shows a consistent reduction after drilling 1000 holes. The tool weight changed from 6.775 g for new tool to 6.481 g after drilling 1000 holes. It indicates a reduction of 3.7%. The friction between tool and workpieces causes an extreme heat and erode some material from the tool thus reducing the weight of the tool. The reduction is mostly occurred at conical and center regions as also obtained in Figure 4. Since the workpiece deposition to the tool may affect on the tool profile and weight, it should be noted that the measured tool weight was a balance of the loss due to tool wear (Miller et al., 2007).

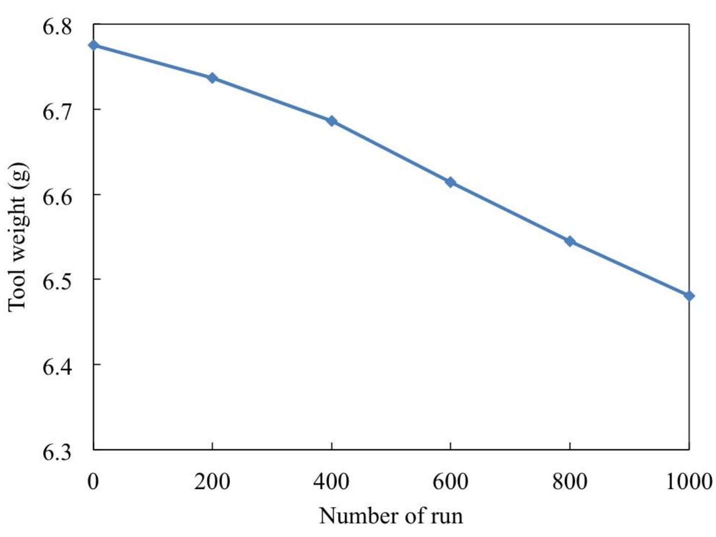

Figure 5: The weight lost until drilling 1000 holes.

The friction-drilled hole is an essential dimensional accuracy that can be affected from worn tool. Figure 6 shows the hole diameter at the number of run n = 1, 200, 400, 600, 800, and 1000 that measured using profile projector. It confirmed that the diameter reduction of drilled hole is significantly affected from the tool profile (Figure 4). The reference diameter is 8 mm based on the diameter of cylindrical region of the drilling tool. It can be observed that a general trend of reducing hole diameter. The first drilled hole is 8.059mm and then it ultimately changes to 8.050 mm and 8.033 for the 200 and 1000 drilled hole, respectively. This small change is due to the lower tool wear in the cylindrical region, which the drilled hole is fully formed at fourth stage of friction drilling process. Although the tool wear is mostly occurred at conical and center regions, the hole diameter is significantly affected by the cylindrical region of drilling tool.

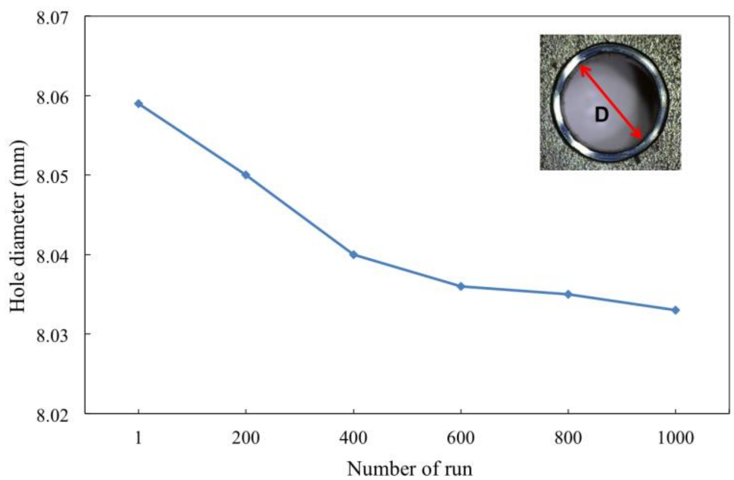

Figure 6: Hole diameter at the number of run.

Figure 7 shows the evolution of adhesive wear that was observed from new tool (n=0) and up to the number of runs n=1000. It found that the white material adhesion from the workpiece to the center and conical regions of drilling tool. The size of area with adhesive material increases with the number of runs. The adhesive material almost covers partial of the conical region after 1000 runs. This material adhesion is due to the high force during initial penetration between center region and workpiece to generate a friction that produces heat for softening the workpieces. It can be seen in Figure 8 that confirmed the high force is generated at initial penetration with thrust force of 2.43 kN and it reduces after the workpieces was soften at second stage of friction drilling process. Figure 9 shows the SEM image and EDS analysis of tool surface at conical region with white material after drilling 1000 holes. It can be noted that the presents of deposited elements from the workpiece of C, Si, and Fe. This result confirms the material transfers from the workpiece to the tool and as an evidence of the adhesive wear on the drilling tool.

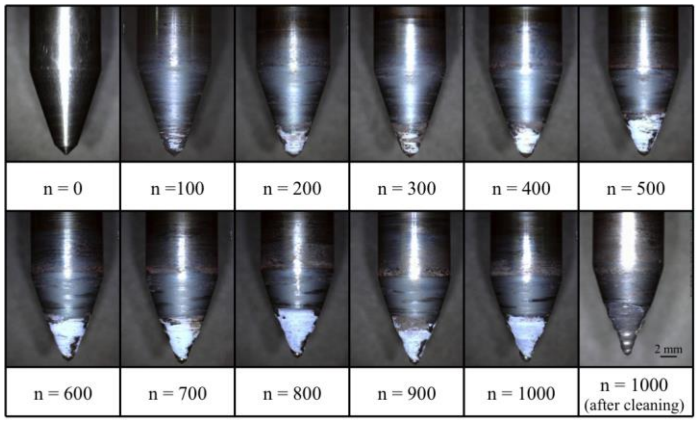

Figure 7: Evolution of adhesive wear.

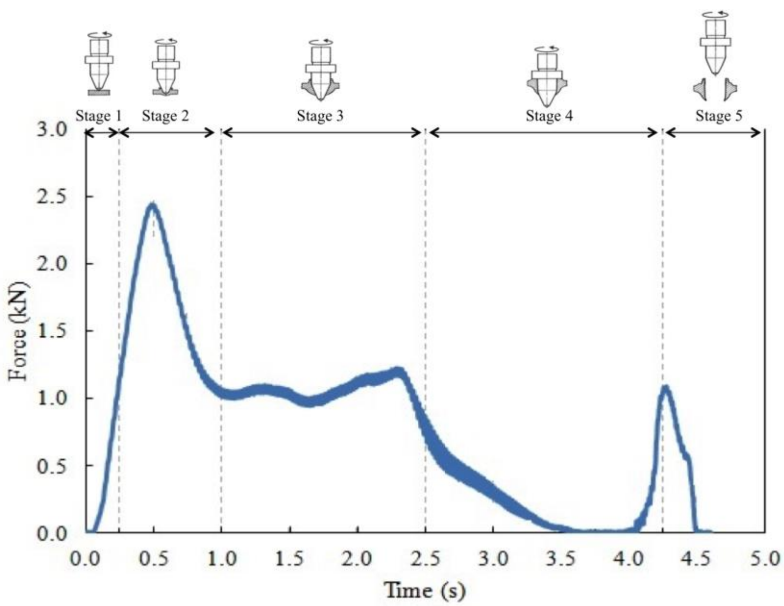

Figure 8: Force generated at initial penetration.

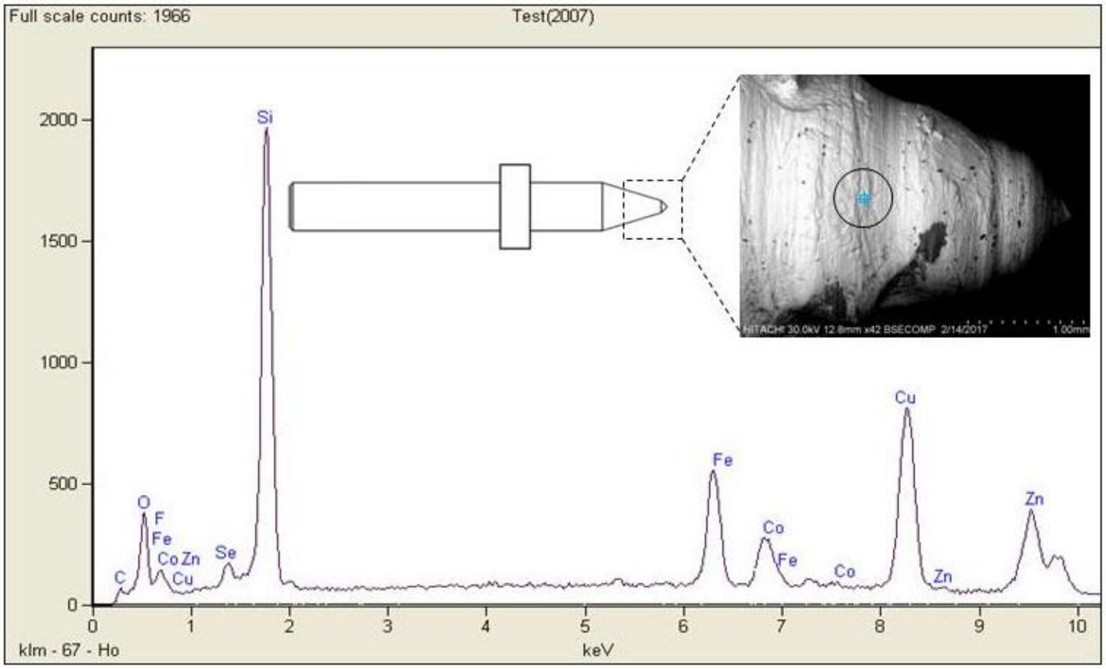

Figure 9: SEM image and EDS analysis.

The optical micrographs of the drilling tool after drilling 1000 holes are shown in Figure 10. It shows the abrasive wear occurred at the center and conical regions of drilling tool. It can be observed the funnel shape and circular grooves at the center region. The conical region has formed a rough, serrated appearance due to the different forms of wear. The circular grooves at the both regions suggested abrasive wear (Miller et al., 2007. This is the form of wear which occurs when a high thrust force generates grooves on center and conical region. The grooves also cause the work-material adhesion to the tool during machining.

Oxidation wear is the identification with a dark burned appearance on the surface of drilling tool as shown in Figure 10. It occurred may due to the high temperature on every friction drilling process but it still not exceeds the melting temperature of workpiece that also can be observed in Figure 7. In addition, Figure 11 shows the element of oxygen is appeared caused by the high-temperature oxidation in the friction drilling process and oxidization on the tool surface after drilling process. Oxidation wear occurred as a chemical reaction between the tool surface and oxygen at high temperature, and it forms an oxides layer on the surface.

Figure 10: Oxidation wear.

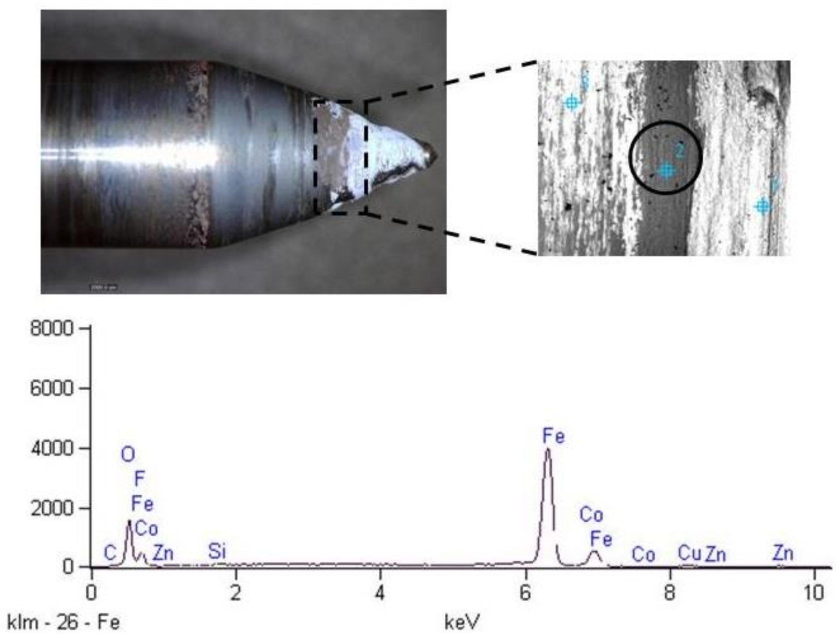

Figure 11: Element of oxygen.

CONCLUSIONS

The characteristics of tool wear in friction drilling using tungsten carbide tool on low carbon steel were experimentally investigated. The main conclusions obtained in this study are as follows:

(a) The tungsten carbide tool proved to be durable and can withstand to drill more than 1000 holes.
(b) The tool profile and weight reduction are affected at the center and conical regions of drilling tool.
(c) The final diameter of drilled hole is not significantly affected by worn tool, since it forms by cylindrical region of drilling tool.
(d) Adhesive and abrasive wears are occurred at the center and partial conical regions of drilling tool due to the high thrust force that generated at initial penetration of friction drilling process.
(e) Oxidation wear forms a dark burned oxides layer that occurred from a chemical reaction between the tool surface and oxygen at high temperature.

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