

Coated carbide drill performance under soluble coconut oil lubricant and nanoparticle enhanced MQL in drilling AISI P20

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Abstract. This research experimentally investigates the performance of a TiAlN coated carbide drill bit in drilling AISI P20 through two different kinds of lubricants, namely; soluble coconut oil (SCO) and nanoparticle-enhanced coconut oil (NECO) under minimum quantity lubrication system. The tool life and tool wear mechanism were studied using various cutting speeds of 50, 100 and 150 m/min with a constant feed of 0.01 mm/rev. Since the flank wear land was not regular along the cutting edge, the average flank wear (VB) was measured at several points using image analysis software. The drills were inspected using a scanning electron microscope to further elucidate the wear mechanism. The result indicates that drilling with the nanoparticle-enhanced lubricant was better in resisting the wear and improving the drill life to some extent

1. Introduction

Metalworking fluids (MWFs) have been well practiced for many years to assist the machining processes for a variety of reasons such as improving tool life, reducing workpiece thermal deformation, improving surface finish and flushing away chips from the cutting zone. Most of the MWFs are mineral oil-based fluids and these fluids are known to increase productivity and quality of manufacturing operations by cooling and lubricating the metal cutting and forming processes [1]. Due to its advantages and high demands in markets, the advent of cutting fluid has become more complex in its composition, which causes significant health and environmental hazards. As a matter of fact, the exposure of MWFs in the working environment represents a massive hazard to the safety of the workers through inhalation and direct skin contact [2]. On one hand, the excessive lubrication system can contaminate the water and soil directly, while, on the other hand, the air can be affected through volatile lubricants or lubricant haze [3]. Therefore, the world wide interest in environmental issues regarding MWFs has encouraged research into new technological developments and using vegetable oils as alternative base oil for environmentally benign lubricants [4]. In general, vegetable oils have excellent properties such as high viscosity index, high lubricity, high flash point, low evaporative loss, high biodegradability and low toxicity [4-5]. However, the vegetable oils are known to possess low thermal, oxidative and hydrolytic stabilities and low-temperature characteristics [6]. The properties of vegetable oils can only be determined by their fatty acid composition. A high content of linoleic acid decreases the thermal oxidative stability, whereas a higher proportion of long chain saturated fatty acids often leads to inferior cold flow behavior [4,7].

During the pre-mineral oil era, coconut oil was indispensable as a lubricant among other widely used vegetable oils such as olive oil, rapeseed oil, etc. It exhibits good lubricant properties such as high viscosity index, high flash point and low evaporative loss [8-9]. A study conducted by Xavior and Adithan [10] showed that coconut oil performed better in turning AISI 304 with carbide tool. It was



postulated that this is due to its thermal and oxidative stability which is comparable to their vegetable-based cutting fluid used in metal cutting industry. Recently, the term “nano-lubricant” represents a lubricant which is used for nano application or a lubricant obtained by the addition of nanoparticles [8]. Several researchers acknowledged that the addition of nanoparticle to the lubricants is effective in reducing wear and friction [11-12]. Hence in this research, nanoparticle-enhanced coconut oil (NECO) has been used to represent the natural coconut oil with copper oxide (CuO) nanoparticles as the additive.

The objective of the present study is to investigate and compare the performance of coated carbide drill under Soluble Coconut Oil (SCO) and Nanoparticle-enhance Coconut Oil (NECO). The growth of flank wear for the coated carbide has been observed and analyzed. In addition, the flank wear mechanism was also studied and examined.

2. Experimental setup

2.1 Materials

AISI P20 was chosen as the workpieces material for the drilling experiment. This chrome-moly alloy steel is generally applied to fill the requirements for the machined cavities and forces used in zinc die casting and plastic molding. The dimension of each workpiece was 150 mm x 150 mm x 40 mm. The chemical composition is given in Table 1.

Table 1 Chemical composition of AISI P20 steel (% wt, ASTM)

C	Si	Mn	Cr	Mo	Ni
0.35-0.45	0.20-0.40	1.30-1.60	1.80-2.10	0.15-0.25	0.90-1.20

2.2 Parameters

The tools used in the experiments were TiAlN coated carbide drills with diameter 8.5 mm. The cutting parameters used in this experiment were a cutting speed of 50 m/min, 100 m/min and 150 m/min with a constant feed rate at 0.1 mm/rev. The hole depth used was three times the diameter of the tool (25.5 mm).

2.3 Preparation of Lubricants

The experiment was carried out using two different types of lubricants, namely; soluble coconut oil (SCO) and nanoparticle-enhanced cutting oil (NECO). These lubricants essentially using coconut oil as the vegetable oil-base lubricant were prepared with additives in order to improve the performance of the lubricants [13]. The lubricants prepared were 500 ml each of SCO and NECO. The SCO was prepared with additives which consist of a mixture of acacia powder, distilled water and lime extract. Acacia powder functions as an emulsifying agent that will dissolve the coconut oil and distilled water thoroughly. Meanwhile, the lime juice extracts which are high in vitamin C content were added as a possible antioxidant agent in the lubricant. The mixing was carried out in the hot plate magnetic stir at a temperature of 55°C in the rotation of 6 rpm. To ensure a proper mixture, the period of mixing was around 30 minutes. It was then left at room temperature for three days in order to ensure the mixture reached the desired assortment. NECO was prepared by thoroughly mixing the coconut oil with the CuO nanoparticles. Commercially available nanoparticles in the range of <50 nm supplied by Sigma Aldrich were used. These nanoparticles were directly added to the coconut oil with 0.5% based on the weight percentage basis [14]. The oil was then agitated using ultrasonic shaker for 1 hour to ensure uniform dispersion and good suspension stability. The temperature was maintained at 60°C.

2.4 Methods

The drilling process was performed on an Akira-Seiki Performa SR3 XP Vertical CNC Milling machine with the aforementioned cutting speed. The lubricants were applied through a UNIST MQL system with the flow rate of 10 ml h⁻¹ with the pressure of 6 bars. A universal Leica microscope was used to observe the wear performance on the cutting tools for every hole interval. Average flank wear of the cutting tool was recorded and reported for analysis. The tool flank wear was measured in accordance

with ISO 3685-1993 standard. Since the width of flank wear was not regular along the cutting edge, the image of flank wear was taken after predefined drilling intervals. The image was then measured at several points by image analysis software. The worn cutting tool was then cut 10 mm from the tool tip by EDM wire cut for further wear analysis through scanning electron microscope. The data was acquired and comparison was made between the drilling that use SCO and NECO as lubricants.

3. Results and discussion

3.1 Growth of the tool wear

Average flank wear (VB_{ave}) of the drill bit was measured at five equidistant points since the flank wear pattern was not regular along the cutting edge. Measurement was taken after predefined 100 drilled holes for each speed and type of lubrication used. The graph of VB_{ave} growth for various cutting speeds and constant feed was plotted for SCO and NECO, respectively. Figure 1 and 2 exhibit the SCO and NECO flank graphs based on the number of holes. It appears that, the drilling at cutting speed of 50 m/min resisted to wear more effectively compared of that for 100 m/min and 150 m/min.

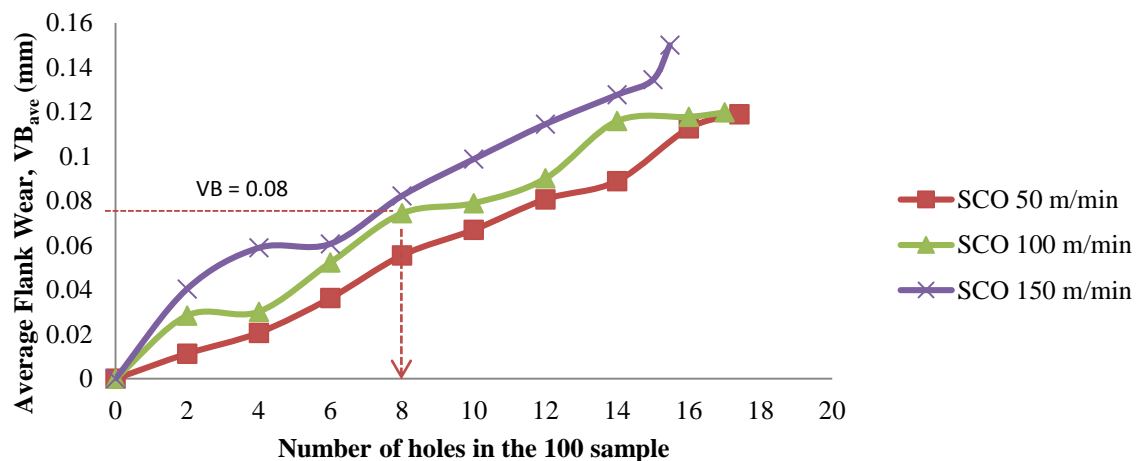


Figure 1: Growth of flank wear with number of holes at cutting speed of 50m/min, 100m/min and 150 m/min and constant feed of 0.1mm/rev with soluble coconut oil (SCO).

The coated carbide performance under the lowest cutting speed of 50 m/min was significantly better than 100 m/min and 150 m/min cutting speed. This indicates that the lowest speed can enhance the drill life by some extent. Additionally, the well broken contact between chip and tool that produce during the drilling may facilitate the penetration of lubricant and thus enhancing the tool life [15]. The performance of drill bit was found to be better compare to the speed of 100 m/min and 150 m/min up to drilling of 41 holes for SCO and 92 holes for NECO. However, a sudden failure at the highest cutting speed of 150 m/min was observed for both lubrications due to chipping which is the main reason for tool wear. Figure 3 shows the image of chipping that was appeared along the cutting edge. The interrupted cutting due to chipping may lead into impact loading on the cutting edge which may further deteriorate the tool life. Therefore, lowest cutting speed of 50 m/min is recommended for both lubricants. This is inline with the suggestion made by Erween and Shariff in their work that drills titanium using coated carbide drill bit [16].

Flank wear vs. number of holes of NECO

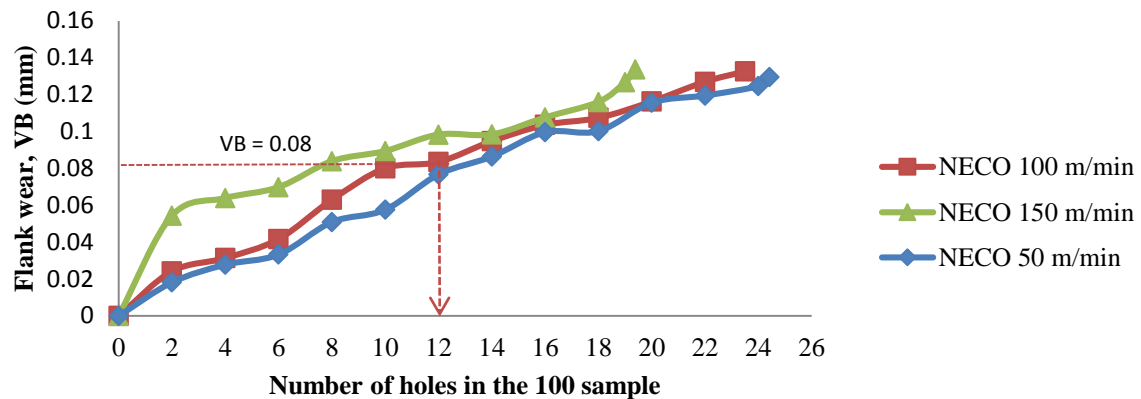


Figure 2: Growth of flank wear with number of holes at cutting speed 50 m/min, 100 m/min and 150 m/min and constant feed of 0.1 mm/rev with Nanoparticle-enhanced Coconut Oil (NECO).

Comparing Figure 1 and Figure 2, it appears clear that the drill life was slightly prolonged when NECO was applied. The wear limit was determined at 0.08 mm. At this stage, the number of holes produced by NECO is 1200 holes up to 400 holes compared to SCO which only produced about 800 holes. It practically shows that the coated carbide drill bit is more resilient under NECO as cutting fluid. Moreover, it is conjecture that the application of NECO seems to encourage the formation of thin film on both tool and work surfaces of tool steel. This is due to its high bonding forces with contacting surface and in turns reduces the area of contact between the tool and the workpiece. Hence, the governing mechanism of tool wear is alleviated and this extends the drill life [17].

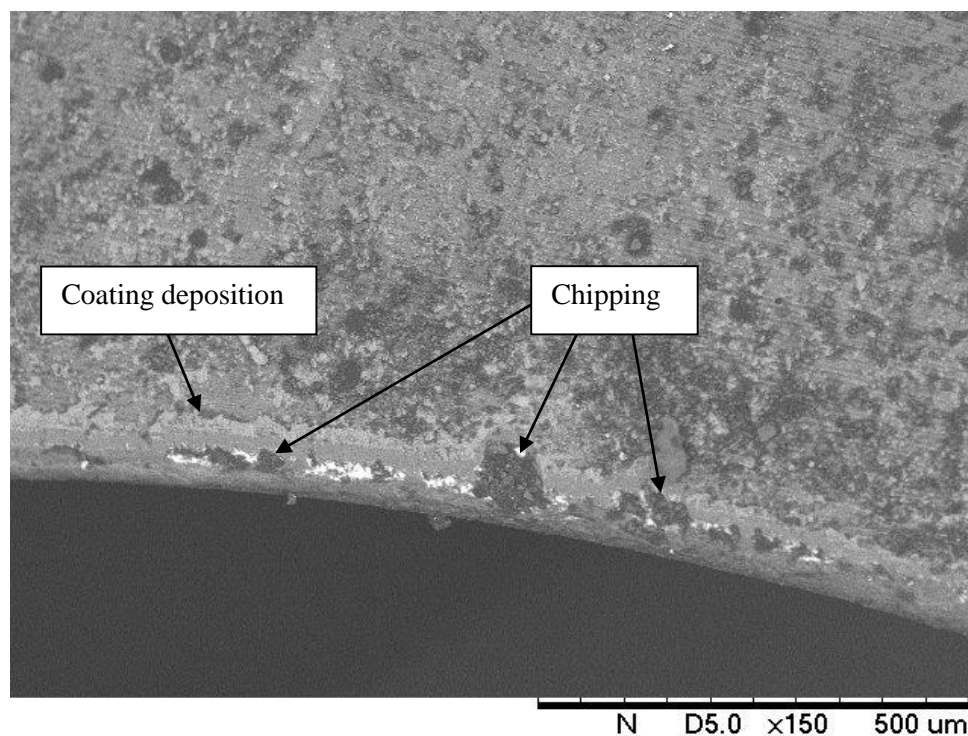


Figure 3. Image of chipping and coating deposition that is observed under SEM along the cutting edge at the speed of 150m/min for SCO.

3.2 Flank wear mechanism

In this study, it was observed that the flank wear most commonly results from abrasion of the cutting edge. Abrasive wear occurs when hard particles abrade and remove coating material from the tool. Figure 4 shows the distribution of flank wear along the cutting edge. The tool wear takes place at the two different parts of the drill tool. One is along the cutting edge and the other one is at the end of the cutting edge near corner of the drill bit. Tool breakage can be seen clearly at the end of the cutting edge. Based on the observation of the tool condition, the coated layer of cutting tool was abraded-off at the beginning stage of first 200 holes results in 0.01 mm flank wear width. It is followed by the flank wear where chipping was formed at the outer cutting edge and also found that the deposition of coated particle on the tool surface as depicted by SEM in Figure 3. The flank wear measured at this stage and a value of 0.07 mm width is obtained after 800 drilled holes. As the drilling process is proceed up to 1200 holes, the crack on the chipping area propagate towards the end of the cutting edge near the corner region and lead to subsurface fatigue stress. This is depicted by SEM micrograph image in Figure 5. The flank wear was up to 0.12 mm width noted at this area. The wear rate increases drastically with the increase of flank wear. It was observed that during drilling, the long thick chips entangled around the drill flute which interrupted the cutting process and caused the pre-mature failure of the drill bit.

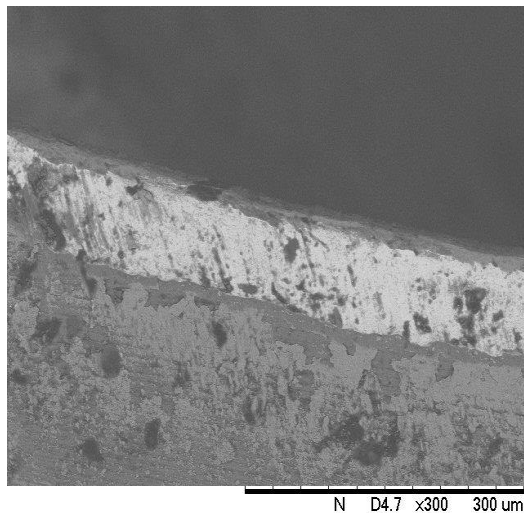


Figure 4: SEM micrograph image of flank wear distribution along the cutting edge.

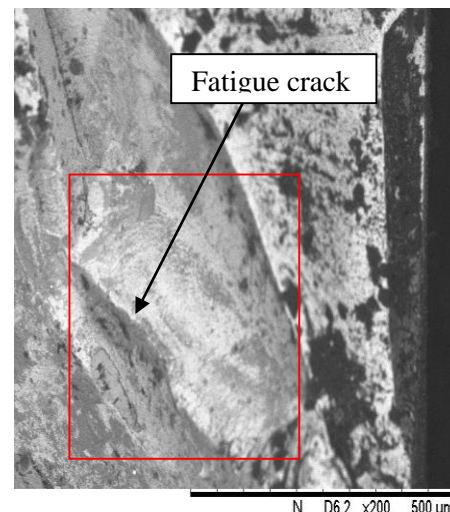


Figure 5: SEM micrograph image of the collapse region.

4. Conclusion

The mechanisms and growth of wear in drilling AISI P20 with TiAlN coated carbide drill have been investigated and reported in this study. The results indicate that lowest cutting speed of 50m/min is recommended in drilling AISI P20. The physical mechanism of flank wear started when the coated layer is abraded-off first. Then, it is followed by the flank wear, and chipping at the outer cutting edge. The micro-cracks around the region of chipping propagate and cause the subsurface fatigue crack and failure of a drill eventually. Importantly, the use of nanoparticle mixed with coconut oil was better in resisting wear effectively and improves the drill life to some extent due to high bonding forces of nanolubricant with contacting surfaces and thus alleviated the contact area between tool and workpiece.

References

- [1] S A Lawal, I A Choudhury and Y. Nukman, International Journal of Machine Tools and Manufacture 52(1) (2012) 1-12.
- [2] D S Sokolović, W Höflinger, R M S Šečerov, S M Sokolović and D Sakulski, Journal of Aerosol Science 61 (2013) 70–80.
- [3] P Nagendramma and S Kaul, Renewable and Sustainable Energy Reviews 16(1) (2013) 764–774.
- [4] N H Jayadas and K P Nair, Tribology International 39(9) (2006) 873–878.

- [5] M Nabeel Rashin and J Hemalatha, *Experimental Thermal and Fluid Science* 48 (2013) 67–72.
- [6] S Z Erhan, B K Sharma and J M Perez, *Industrial Crops and Products* 24(3) (2006) 292–299.
- [7] N M Nasir, A Z Romli and A Wahab, *AENSI Journal* 8(8) (2014) 2589–2593.
- [8] M V Thottackkad, R K Perikinalil and P N Kumarapillai, *International Journal of Precision Engineering and Manufacturing* 13(1) (2012) 111–116.
- [9] N H Jayadas, K Prabhakaran Nair, and A G, *Tribology International* 40(2) (2007) 350–354.
- [10] M A Xavior and M Adithan, *Journal of Materials Processing Technology* 209(2) (2009) 900–909.
- [11] P V Krishna, R R Srikant, and D Nageswara Rao, *International Journal of Machine Tools and Manufacture* 50(10) (2010) 911–916.
- [12] H L Yu, Y Xu, P J Shi, B S Xu, X L Wang, and Q. Liu, *Transactions of Nonferrous Metal Society China* 18(3) (2008) 636–641.
- [13] Y Zhang and M B G. Jun, *Journal of Manufacturing Process* 16(4) (2014) 503–510.
- [14] A V V Koushik, N S Shetty and C Ramprasad, *International Journal on Theoretical and Applied Research in Mechanical Engineering* 1(1) (2012) 95–101.
- [15] R S Joshi and H Singh, *Machining Science and Technology* 18(1) (2014) 99–119.
- [16] EA Rahim and S Sharif, *International Journal of Manufacturing Technology and Management* 17(4) (2009) 327.
- [17] A S David and S A John (2006) 512-521.