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Effects of drilling parameters on drill bit wear of ASTM A36 steel

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ABSTRACT

Drilling is a crucial process in metal manufacturing, with drill bits being key tools for creating holes in workpieces. During drilling, wear of the drill bits occurs inevitably. Several factors affect the wear of drill bits, such as materials, workpieces, and drilling parameters. The impact of these parameters on wear is investigated to understand the effects of drilling parameters on drill bit wear. This study used a diameter of 6 mm of uncoated high-speed steel drill bits to create the hole with 30 mm depth on ASTM A36 steel. The drilling was performed utilizing the DMG Mori DMU-50 5-axis drilling machine at three different levels of spindle speed (800, 1100, and 1400 rev/min) and feed rate (120, 135, and 150 mm/min). The sensor force dynamometer measured the thrust force and the cutting torque during drilling. However, many types of wear occur on drill bits during drilling. This research investigates only flank wear on the cutting edge of drill bits. The flank wear on the drill bits was measured with the overlap image technique using an Olympus SZ61 stereo microscope with a C-P3 OPTIKA digital camera. The results showed that adjusting drill parameters to increase the feed per revolution may result in a higher drill bit flank wear rate. Additionally, to quantify the wear of the drill bit based on the number of holes drilled, both the feed per revolution and the cutting distance per hole must be considered.

Keywords: Drill bits, Drilling parameters, Flank wear, Thrust force, Cutting torque

INTRODUCTION

Drilling is an important machining process for creating holes, with the drill bit being the main tool. However, wear of drill bits during drilling is inevitable. This wear can manifest in various forms, such as crater, margin, chisel, and flank. The most critical criterion for tool life in drilling is flank wear [1-3]. The wear of a drill bit due to usage limits its lifespan and negatively affects the quality of the holes. To address these problems, the wear resistance of drill bits has been improved by focusing on the drill bit material and coatings. Proper drilling parameters can also help reduce drill bit wear. Many research studies have been conducted to understand the effects of drilling parameters on Z that drill bit wear increases with an increase in feed rate, while low feed rates and cutting speeds result in longer tool life. Turgay Kivak et al. [5], Muksin R. Harahap et al. [6], M. Balaji et al. [7], and Nur Munirah Binti Meera Mydin et al. [8] showed that drill bit wear increases with increasing cutting speed. However, previous studies have not fully clarified the effects of drilling parameters on drill bit wear. To improve understanding, some research has considered how drilling parameters influence the forces exerted on the drill bit during drilling, as explored by A. Mohan kumar et al. [9] and Ferit Ficici [10]. They showed that the feed rate affects thrust force more than cutting speed. However, they did not examine the effects of thrust forces on drill bit wear. Consequently, to further clarify the effects of drilling parameters on drill bit wear, we investigated the influence of drilling parameters on drill bit wear and combined the results of both thrust force and cutting torque to enhance our understanding.

MATERIALS AND METHODS

The high-speed steel drill bits manufactured by Nachi Technology Co., Ltd. were used in this work. The characteristics of the drill bits - surface hardness, drill bit diameter, helix angle, point angle per tooth, relief angle, flute width, runout, and radius of the point angle - are shown in Table 1. Surface hardness was assessed using the Future-Tech FM-800 micro-Vickers hardness tester. The drill bit was employed to create the hole on the ASTM A36 steel, each with a depth of 30 mm, utilizing the DMG Mori DMU-50 5-axis drilling machine. The drilling process involved two groups of parameters: the first group operated at three different levels of spindle speed (800, 1100, and 1400 rev/min) with a constant feed rate of 135 mm/min, while the second group operated at three different levels of feed rate (120, 135, and 150 mm/min) with a constant spindle speed of 1100 rev/min, as outlined in Table 2. A control

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experimental condition was chosen for both groups based on the manufacturer's recommendations. The selected rotation speeds and feed rates were intentionally set below and above the manufacturer's recommended values to observe the trends and changes in the performance of the drill bits. The thrust force and torque were measured during drilling using the Kistler 4-component dynamometer (model: 9272). The schematic of the dynamometer and the workpiece setup for drilling is shown in Figure 1. After every 10 holes, the drill bits were visually inspected, and images of the drill bit surfaces were captured using an Olympus SZ61 stereo microscope with a C-P3 OPTIKA digital camera. The captured images were used to measure flank wear by the overlap technique, as shown in Figure 2. Additionally, the flank wear on the cutting edge of the drill was measured at 1 mm from the edge of the drill, following the method used in the works of V. Z. Mehrabad et al. [11].

Table 1 Characteristics of the drill bit.

Surface hardness (HV0.1)	Diameter (mm)	Helix angle (degree)	Point angle per Teeth (degree)	Relief angle (degree)	Flute width (front), (mm)	Flute width (back), (mm)	Run Out (mm)	R -Point angle (mm)
722.33	6.08	31.5	59.2	15	3.83	3.59	0.04	4.66

Table 2 Drilling parameters.

Group	Rotation speed (rev/min)	Feed rate (mm/min)
1	800, 1100, 1400	135
2	1100	120, 135, 150

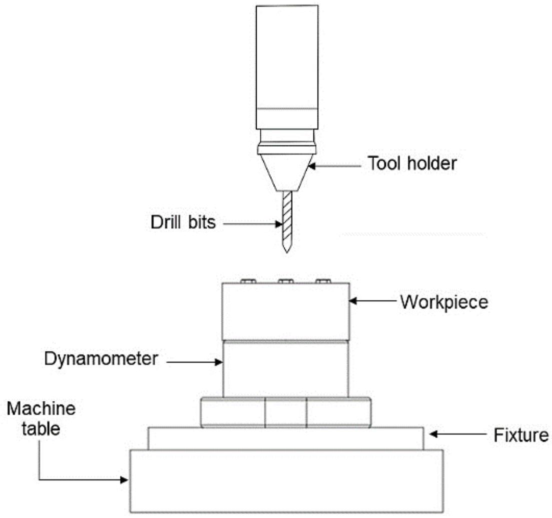
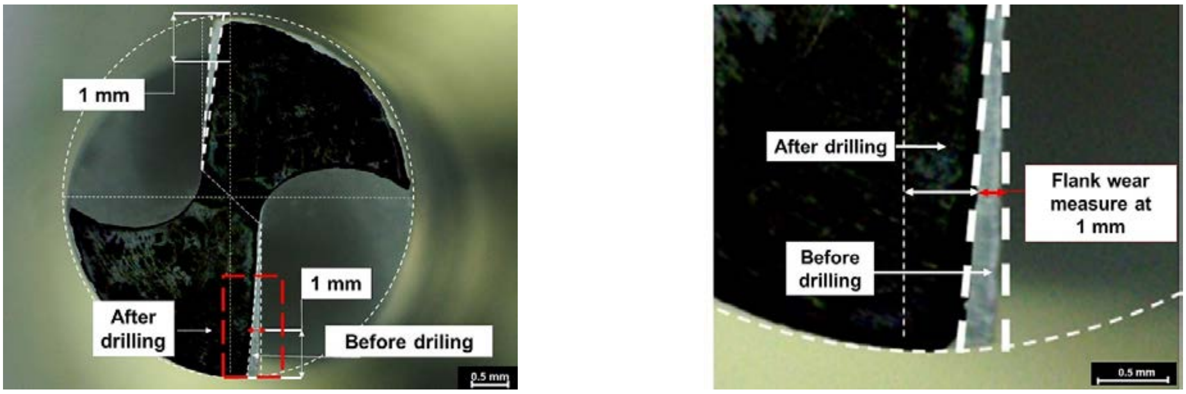


Figure 1 The schematic of dynamometer and workpiece setting for drilling.



(a) The overview of measurement flank wear.

(b) Magnification image of measurement flank wear at the cutting edge.

Figure 2 The front view of the wear drill bits was measured by comparing the worn image before and after drilling the drill bits with the image overlap technique.

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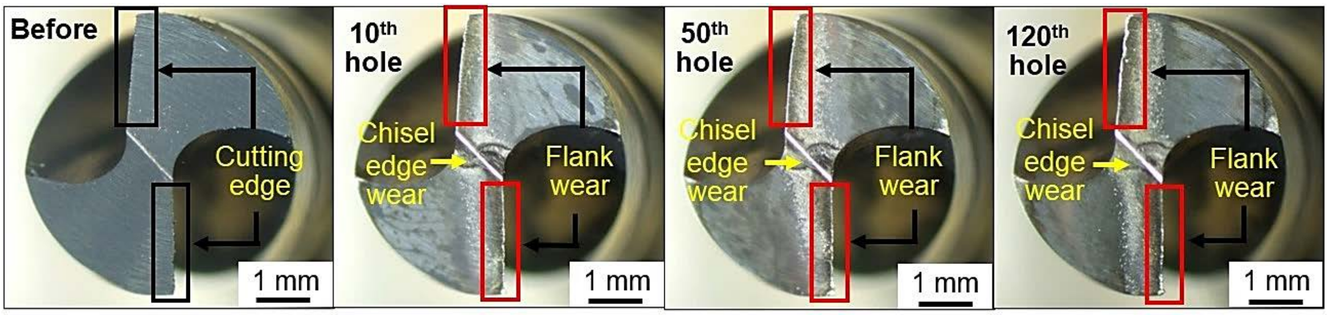


Figure 3 The front view of drill bits before and after use at 10, 50 and 120 holes. Drilling was performed under a feed rate of 135 mm/min and rotation speeds of 1100 rpm.

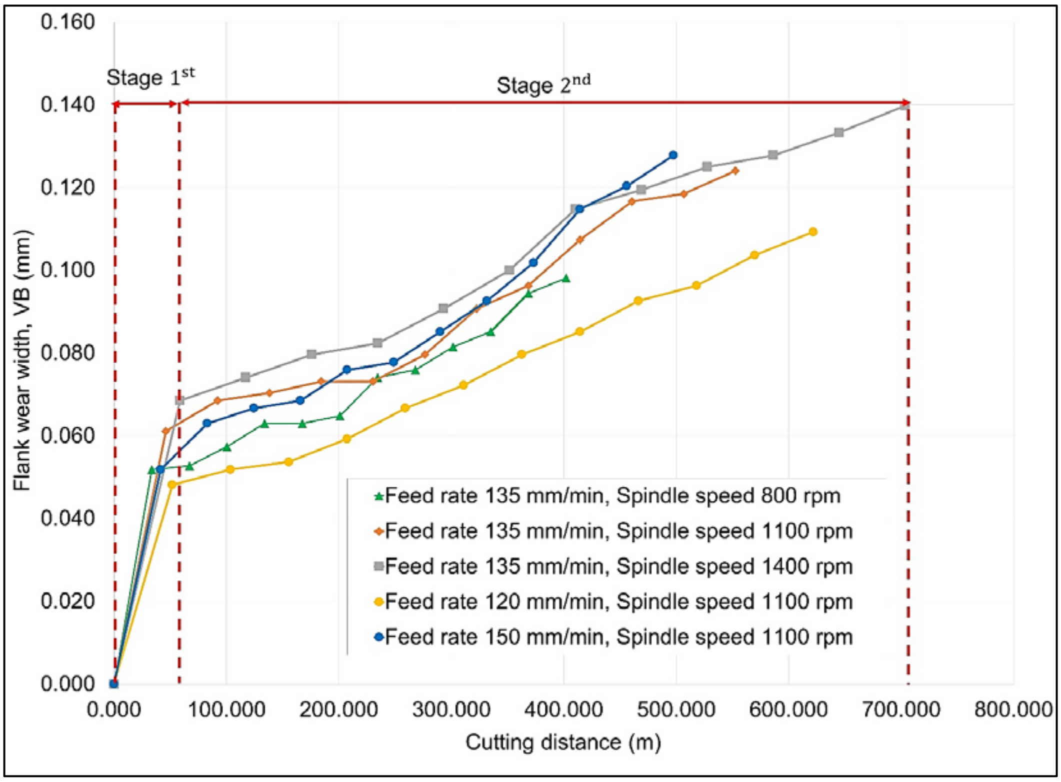
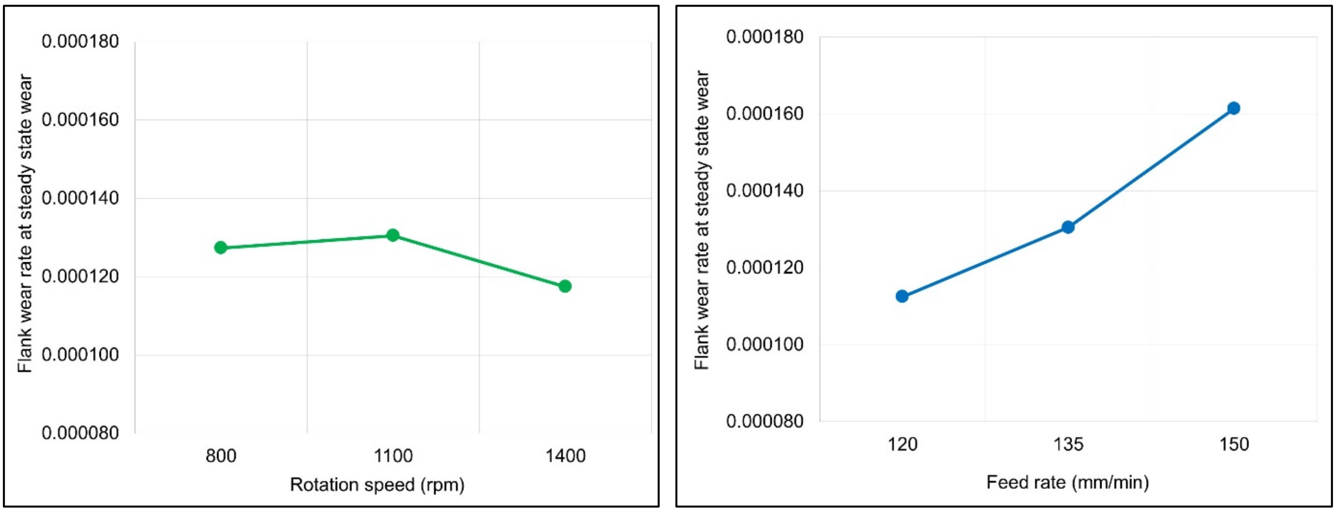


Figure 4 The flank wear of the drill bits at cutting distances with three rotation speeds and feed rates.



(a) Flank wear rate during drilling with difference rotation speed at constant feed rate 135 mm/min.

(b) Flank wear rate during drilling with difference feed rate at constant rotation speed 1100 rpm.

Figure 5 The flank wear rate of the drill bits varies with (a) three rotation speeds and (b) three feed rates.

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RESULTS AND DISCUSSION

Drill bits observation

After drilling every 10 holes, wear on the drill bits was observed visually and measured using an imaging technique with the Olympus SZ61 stereo microscope equipped with a C-P3 OPTIKA digital camera. Figure 3 displays front views of the drill bits captured before and after drilling 10, 50, and 120 holes at the rotation speed of 1100 rpm and the feed rate of 135 mm/min. It was observed that initially, the cutting edge of the drill remained a straight line, but gradually transformed into a jagged line with increased drilling, indicating an increase in metal loss termed as flank wear. Notably, after drilling 50 holes, significant metal loss was evident at the cutting edge of the drill bits. Additionally, streaky scratches on the front surface of the drill indicated abrasive wear on the cutting edge. The observed changes in the cutting edge were consistent across all drilling parameters. However, the wear width of the drill was not visually discernible, making it challenging to determine which drilling parameters affected drill bit wear more significantly. Therefore, the numerical values of drill bit wear are measured and are presented in section wear of drill bits of the results.

Wear of drill bits

The wear of the drill bits was measured using an image overlap technique after every 10 holes drilled. To understand the effects of the drilling parameters on the wear of the drill bits, the flank wear is presented in correlation with the accumulated cutting distance, which is defined by the length of the moving cutting edge relative to the cut materials. The flank wear of the drill bit at accumulated cutting distances under various drilling conditions is shown in Figure 4. From Figure 4, we can observe that increasing the accumulated cutting distance increases flank wear. However, when we investigate the slope of the flank wear curve, we can divide the curve into stages with different slopes. This indicates that the flank wear of the drill bit during drilling occurs in two stages. In the initial stage, from the start of drilling to the first 10 holes, the flank wear of the drill bits occurs at a higher rate than in the second stage.

This is because the drill bit is acclimating to the workpiece, causing the cutting edge of the drill bits to be a jagged line, as shown in Figure 3. Later, the drill bits enter the second stage, where the wear increases only slightly despite the increasing accumulated cutting length. This stage is known as steady-state wear. To understand the effects of drilling parameters on the wear of the drill bit, the wear rate, determined by the slope of the wear curve in the second stage in Figure 4, was analyzed. It was found that the wear rates in the second stage under different drilling conditions were not similar. Figures 5(a) and 5(b) show the flank wear rate of a drill bit at three different rotation speeds and three different feed rates, respectively. From Figure 5(a), it can be observed that increasing the rotation speed is likely to decrease the wear rate. In contrast, Figure 5(b) shows that a higher feed rate clearly increases the flank wear rate. Because the drilling parameters used in this study are not the physical parameters needed to understand their effects on the flank wear rate, the flank wear rate was plotted against the feed per revolution, which is the physical parameter that reflects the amount of metal removed per revolution, as shown in Figure 6. It can be seen that increasing the feed per r

Thrust force and cutting torque during drilling

In order to more deeply understand the effects of drilling parameters on the wear of the drill bit, thrust force and cutting torque were investigated. Figure 7 shows examples of thrust force and cutting torque during drilling at a rotation speed of 1100 rpm and a feed rate of 135 mm/min. Figure 7 indicates that the characteristics of the thrust force and cutting torque of the drill bits during drilling can be divided into four main stages. In stage A, the thrust force and cutting torque increase rapidly to a peak. These occurred when the drill bit touched the surface of the workpiece until the tip of the drill bit is fully embedded in the workpiece, causing a gradual increase in thrust force, and cutting torque. Subsequently, the thrust force and cutting torque enter stage B as the drill bit tip is thoroughly drilled into the workpiece. Stage B's thrust force and cutting torque decrease towards a steady state, stage C. In stage C, the thrust force and cutting torque remain constant until the drill bit reaches the predetermined depth. Finally, in stage D, the thrust force and cutting torque sharply decrease as the drill bit moves out of the workpiece. From the thrust force and cutting torque characteristics during drilling, it can be recognized that the thrust force and cutting torque in stage C represent the forces involved in cutting ASTM A36 steel under various drilling conditions. Figure 8 shows the effects of rotation speed and feed rate on the thrust force and cutting torque, respectively. Figure 8 shows that the thrust force and cutting torque during drilling decrease with increasing rotation speed and decreasing feed rate.

To understand the results of drill bit wear and force during drilling, the relationships between forces at steady state wear and flank wear rate and the relationship between feed per revolution and forces at steady state wear were plotted and analyzed as shown in Figures 9 and 10. Figure 9 shows the relationship between thrust force and cutting torque, which affects the flank wear rate. As demonstrated in Figure 9, an increase in both thrust force and cutting torque increases the flank wear rate.

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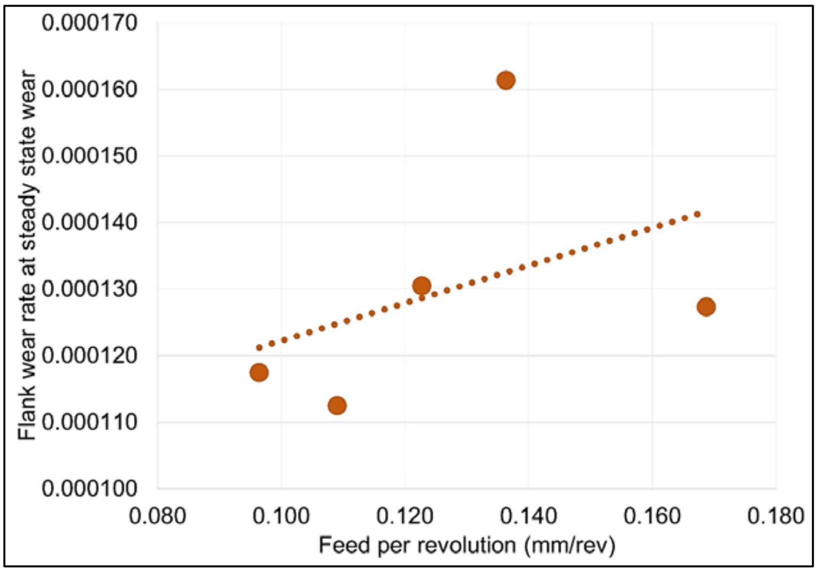
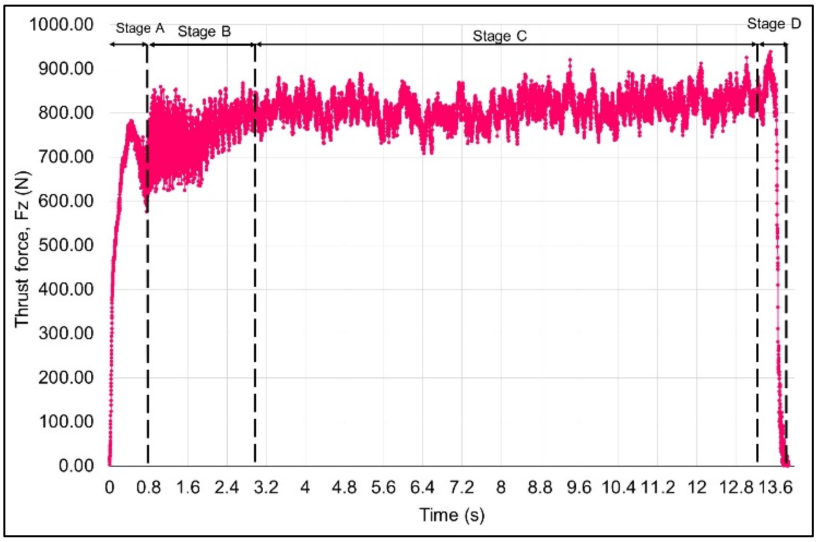
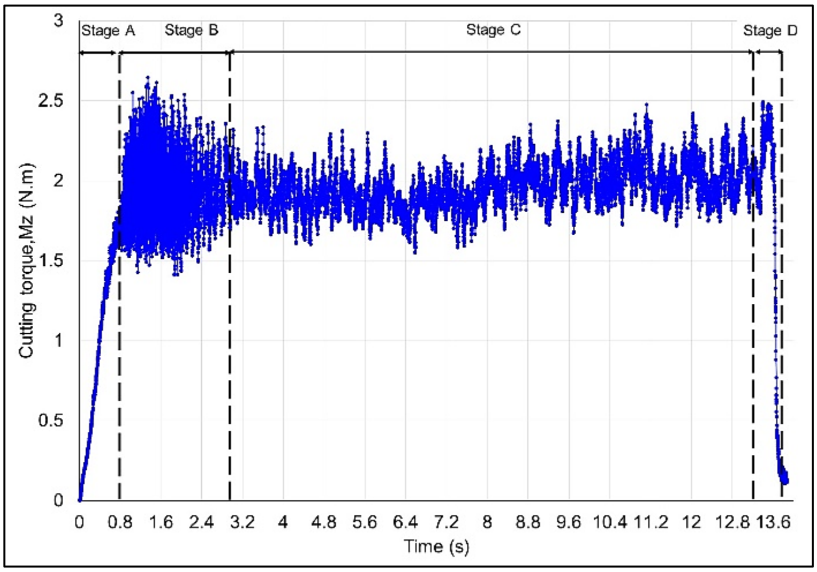


Figure 6 Flank wear rate at steady state wear various feed per revolution .



(a) Thrust force



(b) Cutting torque

Figure 7 The example of (a) thrust force and (b) cutting torque during drilling as 1 hole with 1100 rpm of rotation speed and 135 mm/min of feed rate.

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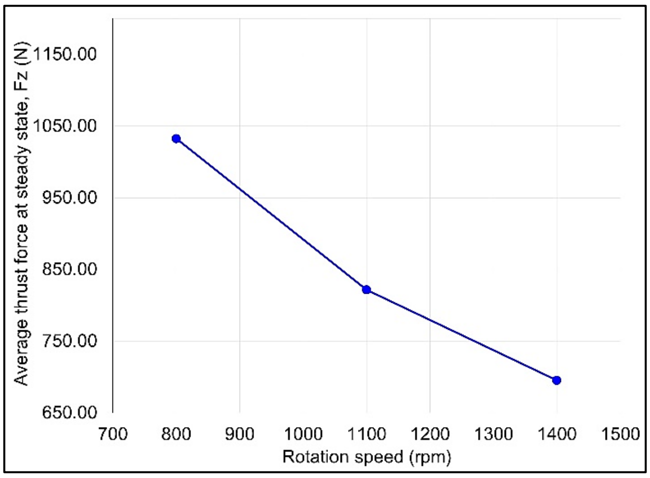
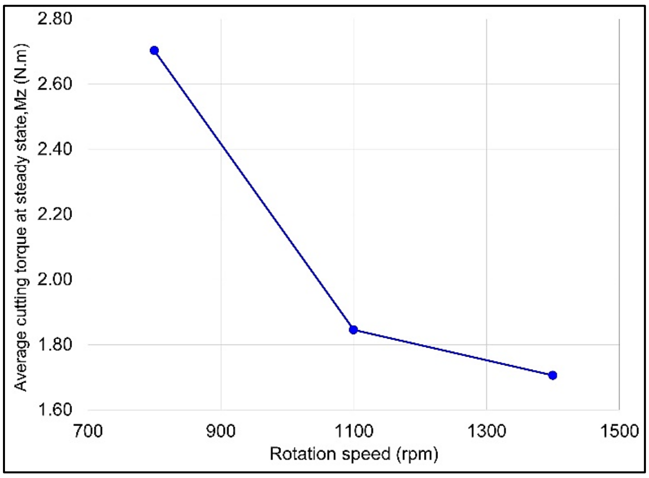
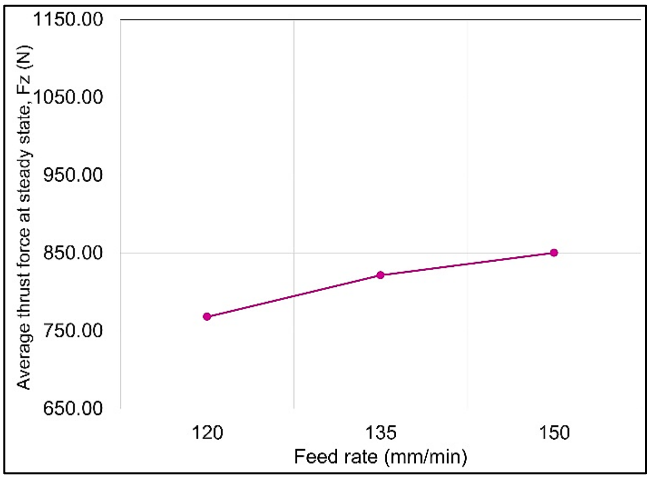


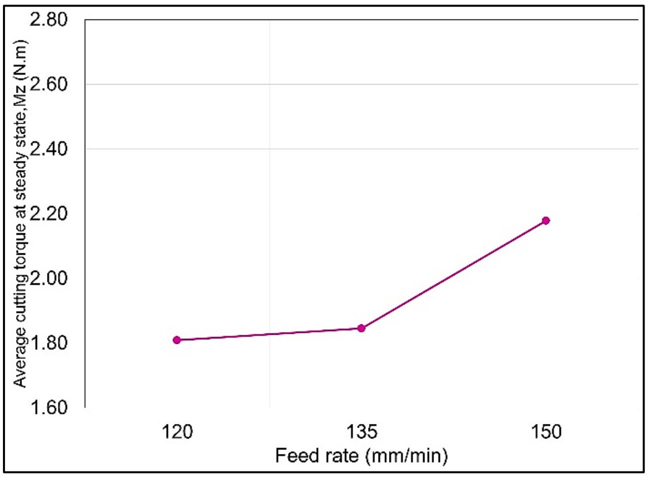
(a) Thrust force



(b) Cutting torque

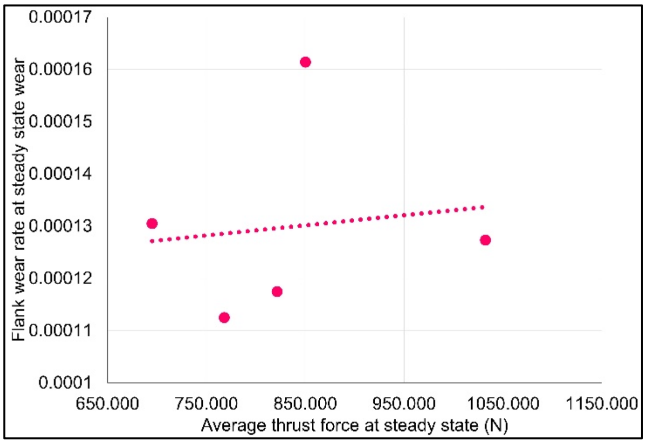


(c) Thrust force

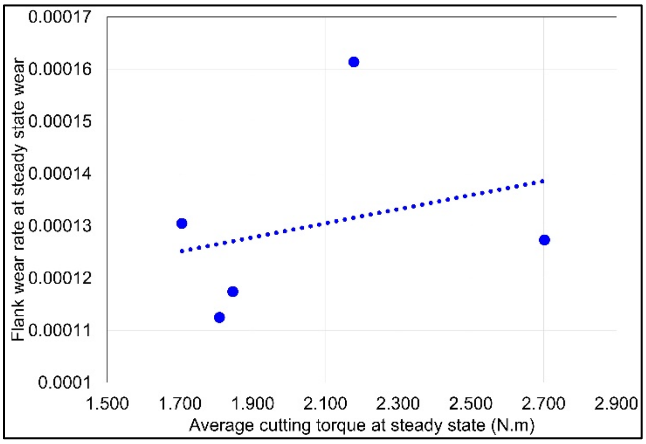


(d) Cutting torque

Figure 8 The average of (a,c) thrust force and (b,d) cutting torque of drill bits drilling at 3-13.3 seconds with three rotation speeds and feed rates.



(a) Thrust force



(b) Cutting torque

Figure 9 The average (a) thrust force and (b) cutting torque on flank wear rate at steady state wear.

This is because the flank wear of the drill bit is a type of abrasive wear that generally increases with the force exerted between the cutting tool and the workpiece. Figure 10 shows that a higher feed per revolution results in higher thrust force and cutting torque. Therefore, it can be recognized that adjusting drill parameters to increase the feed per revolution may result in a higher flank wear rate of the drill bit. Additionally, if we want to quantify the wear of the drill bit by the number of holes created, both the feed per revolution used and the cutting distance per hole must be considered.

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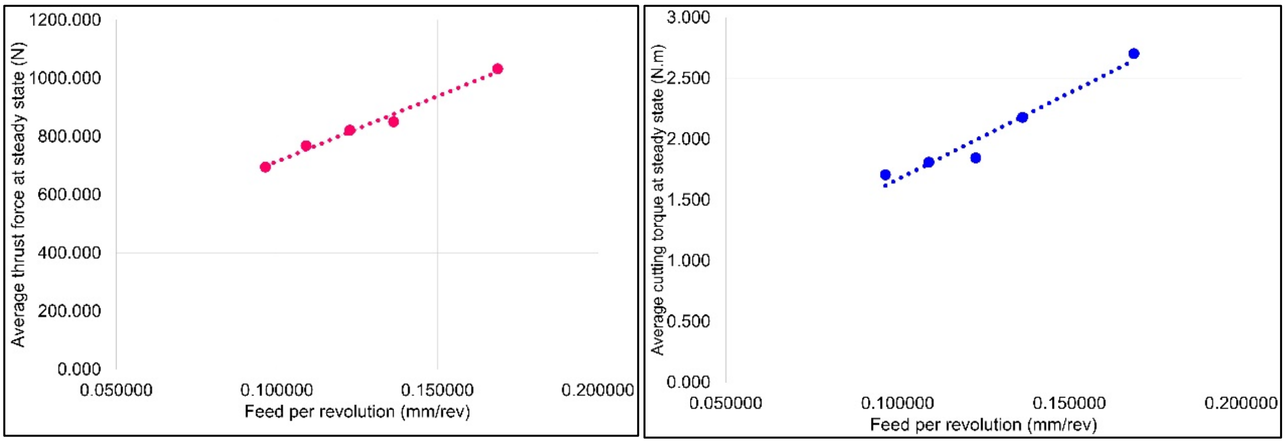

(a) Thrust force (b) Cutting torque

Figure 10 Effect feed per revolution on (a) thrust force and (b) cutting torque.

CONCLUSIONS

This study investigated the influence of feed rates and rotation speeds on drill bit wear. Thrust force and cutting torque during drilling were recorded, and their relationships with steady-state flank wear rate were analyzed to explain the wear of the drill bit. It can be recognized that adjusting drill parameters to increase the feed per revolution may result in a higher drill bit flank wear rate. Additionally, to quantify the drill bit's wear by the number of holes created, both the feed per revolution used and the cutting distance per hole must be considered.

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REFERENCES

1. Sandvik Coromant. Drilling formulas and definitions [Internet]. US - Mebane, NC: Sandvik Coromant; Available from: https://www.sandvik.coromant.com/en-us/knowledge/machining-formulas-definitions/drilling-formulas-definitions.
2. Mohammed T, Hayajneh M. Prediction of cutting tool life in drilling reinforced aluminum alloy composite using a fuzzy method. Int J Mater Metallurgical Eng. 2016;10(4):431-7.
3. ISO (International Organization for Standardization). Tool-life testing with single-point turning tools (ISO 3685). 2nd ed. Geneva: ISO; 1993.
4. Sultana AZ, Sharif S, Kurniawan D. Effect of machining parameters on tool wear and hole quality of AISI 316L stainless steel in conventional drilling. In: 2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015; 2015 Feb 4-6; Bali, Indonesia: Elsevier B.V; 2015. p. 202-7.
5. Kivak T, Habali K, Seker U. The effect of cutting parameters on the hole quality and tool wear during the drilling of Inconel 718. G U J Sci. 2012; 25(2):533-40.
6. Harahap MR, Nasution AH, Napid S. The effect of cutting speed on the wear and tear of Dormer A100 Brazil drill bit applied to gray cast iron. Int J Res Rev. 2022;9(12):586-91.
7. Balaji M, Venkata Rao K, Mohan Rao N, Murthy BSN. Optimization of drilling parameters for drilling of Ti-6Al-4V based on surface roughness, flank wear and drill vibration. Meas. 2018;114: 382-9.
8. Mydin NMBM, Dahnel ANB, Raof NA, MK NK, Mokhtar S. The effect of cutting parameters on tool wear in drilling aluminium 7075. Mattingley Publishing Co Inc. 2022;83:1274-80.
9. Mohan Kumar A, Parameshwaran R, Rajasekar R, Harissh Ragavendra VC, Praveenraj N. Effect of thrust force, torque, and induced temperature on Kevlar reinforced composites during drilling process. Mater Today Proc. 2021;45:522-8. Available from: https://doi.org/10.1016/j.matpr.2020.02.162.
10. Ficici F. Investigation of thrust force in drilling polyphthalamide (PPA) composites. Meas. 2021; 182.
11. Zakeri Mehrabad V, Pourmostaghimi V. Tool wear modeling in drilling process of AISI1020 and AISI8620 using genetic programming. Adv Des Manuf Technol. 2017;10(1):93-100.

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