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Effect of rake angle and feed rate on tool wear and surface topography for different chip size in machining carbon steels

Mohd Fawzi Zamri, Ahmad Razlan Yusoff *

College of Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, MALAYSIA.
*Corresponding author: razlan@ump.edu.my

KEYWORDS

Turning process
Rake angle
Tool wear
Surface topography
Dry machining

ABSTRACT

This paper proposes tool wear and surface topography analyses in cutting carbon steels 1045 that producing different chip types. The problem of continuous chip due to the different rake angle and feed rate cause the reduction of the surface quality and tool life. The cutting rake angle is set based on the difference angle of shim support for the tool holder. Beside rake angle, different feed rate can improve the surface topography and the tool wear. Tests are carried out using carbon steel 1045 as workpiece material and chip breaker CNMG 120412 as tool insert under dry machining conditions. Results indicated that the lowest the tool wear, the better surface topography produced from the segmented chip at feed rate 0.4 mm/rev and a rake angle −9°. The effect of rake angle and feed rate overcome the problem of continuous chip that associated with low tool wear and surface topography.

1.0 INTRODUCTION

Processing raw workpiece materials into a final product that embodies top tier qualities are achievable through excellent execution of machining. Study finds cutting tool wear is important aspect of machining as it has the ability to influence the quality of finish product especially on the surface finish. Besides that, it also able to influence the productivity of manufacturing processes (Sani et al., 2019). There are also other aspects that identified in hard machining process as notably sensitive to numerous technological parameters and their applications (Ajaja et al., 2019). These aspects such as parts' surface integrity (M'Saoubi et al., 2008 and Guo et al., 2009), machinability indexes (Bartarya et al., 2012 and Chinchanikar et al., 2015) and ecological trends

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(Krolczyk et al., 2019) have been extensively studied and proven as significantly sensitive on hard machining process. Others important aspects in industrial manufacturing processes are to improve product quality and to preventing production downtime. Therefore, different cutting-edge microgeometries have been designed differently to hold out against the high cutting pressure and minimise cutting tools failure during machining materials that difficult to cuts (Sulaiman et al., 2021)

On another angle, different cooling and lubrication techniques such as dry, flood and minimum quantity of lubrication based nanofluid (MQL-nanofluid) have been studied by Adel et al. (2019) to observe the effectiveness of those techniques when turning AISI 1045 steel. Zhang et al. (2016) conduct a study on machining a hardened AISI 1045 by using dry cutting method in understanding the formation of serrated chips. Sulaiman et al. (2021) found that MQL or dry conditions should replace current technique of using hazardous lubrication systems with less harmful lubrication techniques.

Besides that, Pervaiz et al. (2016) agreed that lower energy consumption can be achieved with high value of cutting speed that resulted lower value of cutting force. Ye et al. (2012) supports the finding and claimed that high cutting speed promotes low surface finish that is indirectly leads to a higher temperature between tool and chip. The application of microgroove texture on cutting tools can maximise and prolong tool life as it will influence minimal energy consumption during cutting AISI 1045 steel. Thus, in this case, replacing cutting tip is not necessary.

The transitions from continuous to segmented chip has been predicted by Devotta et al. (2020) who applied ductile damage modelling approach with two different initiation strain models based on different rake angle and feed at constant velocity. In another study, Shao and Chi (2019) had discussed on the influence of processing features based on rake angle impact and found that adjustable chip breaker influences the good chip breaking impact under different cutting variable. Wu et al. (2020) also conduct a study to understand the impact of radius chip curl curvature influenced on chip breaker and use finite element simulation method to analyse the impact. In preventing tool failure that will affect machining performance and the quality of the final part of a product, it is important to predict tool wear. This is due to various defects such as flank wear and crater wear that often occur during machining processes as it affected by surface integrity and dimensional accuracy (Maruda et al., 2017). To prevent unnecessary failure, Wang et al. (2019) also conducted a study by selecting wide range of tool wear ranging of more than 0.10 mm to less than 0.25 mm.

In meeting the requirements of machining quality, accuracy, production time and cost of Computer Numerical Control (CNC) turning, all cutting variables should be evaluated properly. Lan et al., (2018) define speed, feed rate and cutting depth are control variables while tool wear is machining quality. Furthermore, different approximation or optimisation techniques were applied by Ahmad et al. (2015) to study the surface roughness (SR) of AISI 1045 steel when machining process is done.

In industrial manufacturing processes, it is important to tackle issues of improving product quality and prevent production downtime. The possibility of tool's failure and surface quality of machine part is found as directly proportional to the increasing of continuous chip. Production performance and the quality of surface finish will also be affected by low endurance limit of usage insert. The present paper study the effect of rake angle of cutting tool and feed rate in machining carbon steel 1045 to chip produced based on Zamri and Yusoff (2019). In comparing chip formation between segmented and continues chips, and the relationship between performance of tool wear and manufacturing processes' surface integrity are further evaluated.

2.0 EXPERIMENTAL PROCEDURE

A CNMG 120412 PM 4325 chip breaker and a DCLNL 2525M 12 tool holder of commercially available turning tool were used in the present study. Table 1 shows the insert specifications. The insert was used to face a 1045 solid round bar of carbon steel. The diameter and the length of the workpiece are 90 mm and 125 mm, respectively. Table 2 provides the chemical composition and mechanical properties of AISI 1045. Figure 1 shows additional support for the tool holder for initially decreasing the rake angle from $-6°$ to $-9°$. The cutting process was conducted at a persistent cutting speed of 275 m/min with a cutting depth of 1.0 mm. Table 3 shows the machining parameter under dry condition. The feed rate used were 0.2 mm/rev and 0.4 mm/rev. The material removed volume (MRV) used for this study are 34.50, 69.00, 103.50, 138.00 and 172.5 mm^3 as cycle 1, 2, 3, 4, and 5.

Table 1: Insert specifications.

Insert code	CNMG 12 04 12 – PM 4325
Carbide grade	4325
Coating	CVD TICN+AL2O3+TIN
Corner radius	1.1906 MM
Insert thickness	4.7625 mm

Table 2: Chemical composition and Mechanical properties of AISI 1045.

Elements	**Chemical composition %**	**Proof strength (0.2% yield) MPa**	**Tensile strength MPa**	**Elongation %**	**Hardness kgf/mm²**
C	0.45				
Si	0.25				
Mn	0.71				
P	0.03	410	640	14	187
S	0.035				

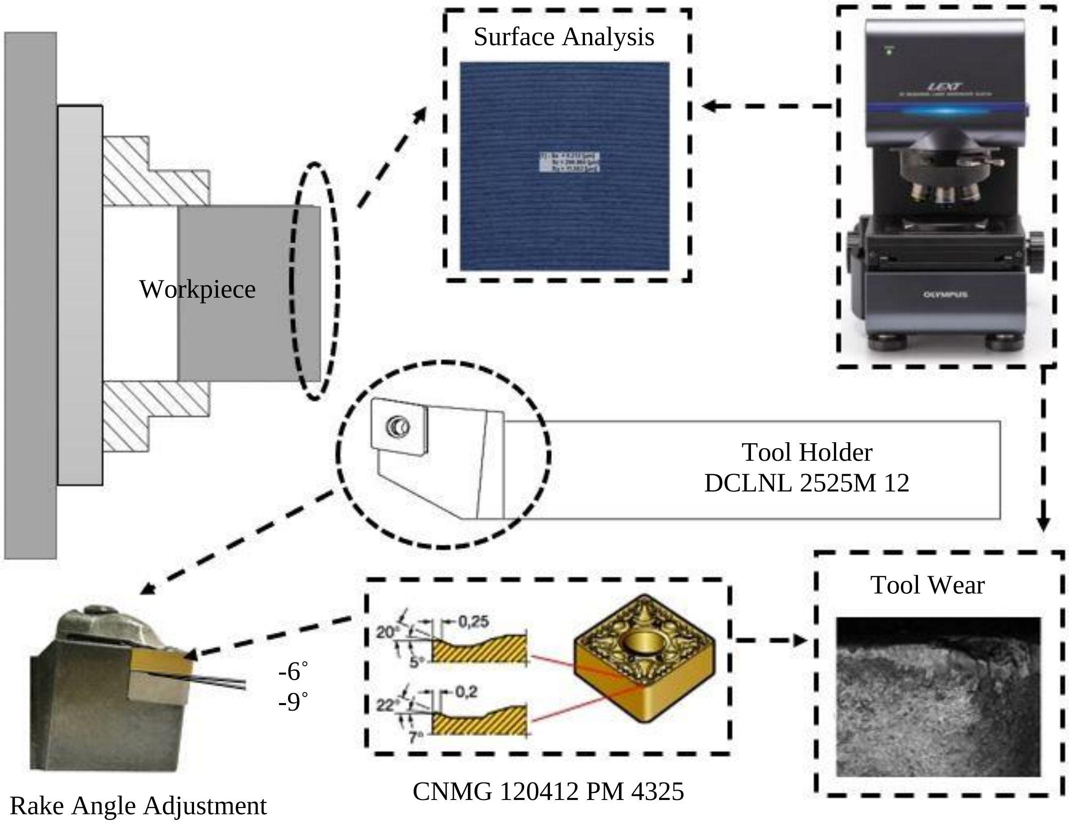
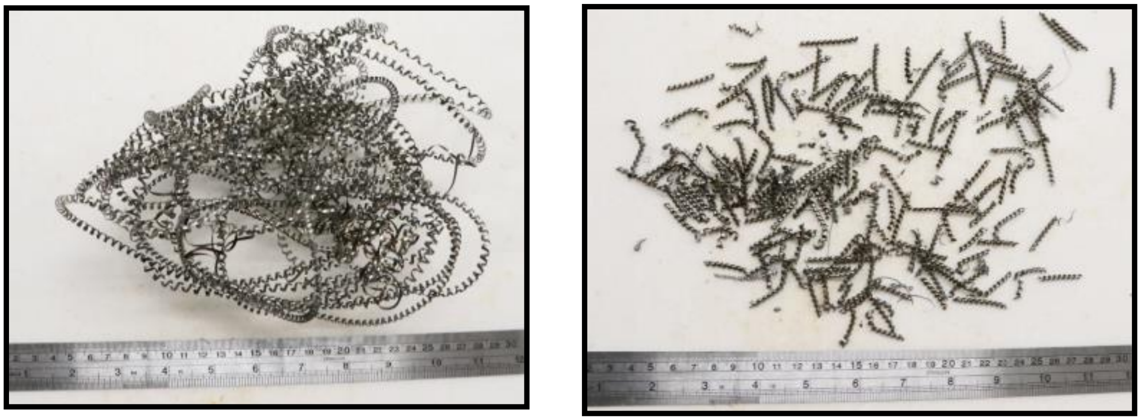


Figure 1: Experimental setup.

Table 3: Cutting parameters.

No.	Cutting speed (m/min)	Feed rate (mm/rev)	Rake angle (˚)	Material removal volume, MRV (mm^3)				
1	275	0.2	−6	34.5	69.0	103.5	138.0	172.5
2	275	0.4	−9	34.5	69.0	103.5	138.0	172.5

For this experiment, the machining parameter have been selected based on previous research (Zamri and Yusoff, 2019). The experiment was started after, cutting speed and feed rate was set up on the CNC lathe machine. After the cutting operation for the first specimen is completed, the feed rate was changed from 0.1 to 0.2, 0.3, 0.4 and 0.5 mm/rev, respectively. The value was chosen based on the recommendation made by the tool maker. Then, the chips produced from the material were collected and tabulated. The test is repeated for different rake angle values. In this project, -ve rake angle was chosen. The original rake angle from tool holder with flat shim is -6 °. Then, new shim with an angle of 3 ° was fabricated for -3 ° of rake angle. Then, for rake angle of -9 °, and -12 ° the shim with angle -3 ° and -9 ° were fabricated. It was resulting the best rake angle is -9 ° with low of chip length. Meanwhile, the optimum feet rate was 0.4 mm/rev. During the machining process, the chips removed from the workpiece produced much strain energy due to plastic deformation with segmented chip, as shown Figure 2b. Meanwhile the chip produce for the parameter feed rate 0.2 mm/rev and rake angle -6 ˚ was continuous chip as shown in Figure 1a. Based on the continuous and segmented chip produced from experiment, tool wear and surface topography effects were analysed in current study.



(a) Feed rate = 0.2 mm/rev and rake angle = −6°

(b) Feed rate = 0.4 mm/rev and rake angle = −9°

Figure 2: Chip type from the two experiments (Zamri and Yusoff, 2019).

The tool wear length was measured with measurements outside the insert using a LEX optical microscope with a magnification of 20,000. A standard measurement of tool life is flank wear length is 0.3 mm or maximum length is 0.6 mm in accordance with ISO 3685. Surface topography as average value S_A was measured on the cutting surface using a laser scanning microscope at a magnification of 5,000. Additionally, the types of chips were compared by conducting two experiments to validate the machining effect on tool wear length and surface topography on workpiece during process.

3.0 RESULTS AND DISCUSSION

Figure 3 shows tool wear length at different material removal volume, whereas Figure 4 shows surface topography at different material removal volume. Tool wear length in experiment 1 was initially short compared with that in experiment 2. In experiment 1, tool wear length was initially 0.086 mm and increased by 23.26% averagely. In experiment 2, tool wear length was initially 0.094 mm, but in the next cycle, it increased only by 19.5% averagely. It shows a better result with decreasing tool wear length between the two experiments due to higher feed rate after cycle 3 MRV of 105 x 10^5 mm^3 (Talib, N. A., 2010). At initial cycle of MRV, the difference between experiments 1 and 2 is approximately 8.5%.

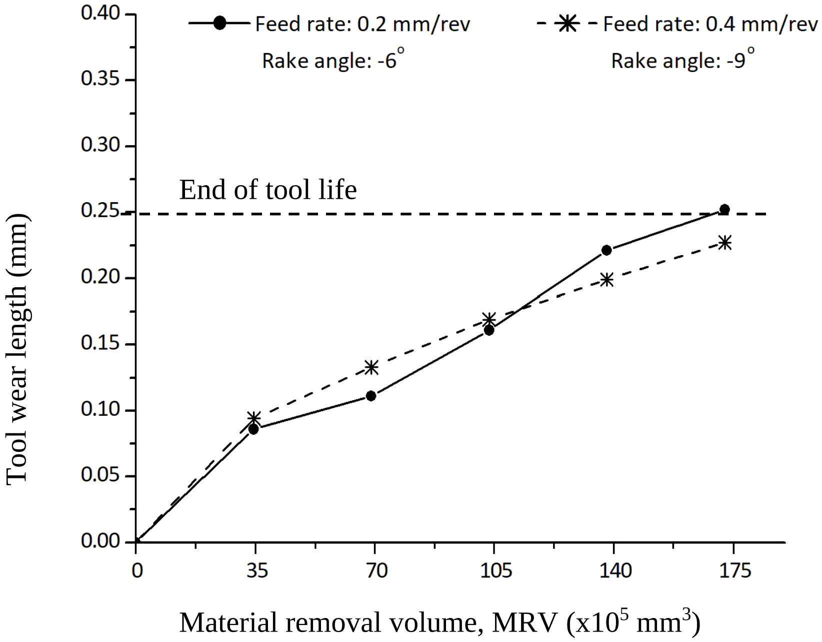


Figure 3: Tool wear in different material rate volume.

Figure 2 shows this difference increased to 9.9% at cycle 5 of 172.5 x 10^5 mm^3. At cycle 1, the tool wear for high feed (experiment 2) is higher than the lowest feed rate (experiment 1). However, at cycle 5, the tool wear decreased for the high feed rate. The decrease of the rake angle to −9° improved tool wear length despite a high feed rate.

Average surface topography S_A in experiment 1 has a lower value compared with that in experiment 2 initially. In experiment 1, the initial S_A was 5.060 µm and increased by 15.49% averagely. In experiment 2, S_A was initially 7.523 µm. However, in the next cycle, S_A increased by 6.74% in a stable manner. At cycle 1, the gap difference between experiments 1 and 2 increased by 32.74%; however, at cycle 5, the difference is decreased by 2.66% to 10.018 µm, as shown in Figure 3. At cycle 1, the surface topography for feed rate of 0.4 mm/rev (experiment 2) is higher than that in experiment 1. However, at cycle 5, the surface topography decreased the percentage for higher feed rate (Kumar et al., 2021). The decrease of rake angle to −9° improved the surface topography value despite a feed rate of 0.4 mm/rev.

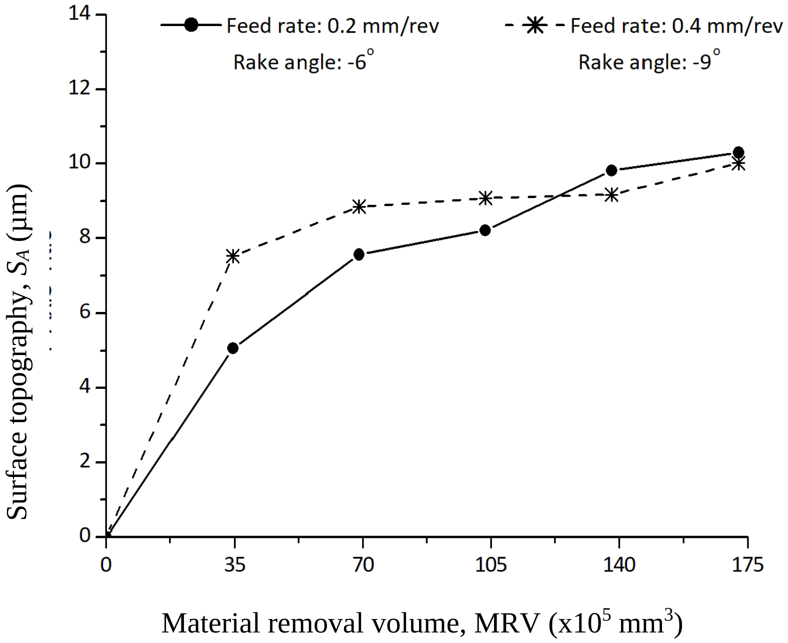
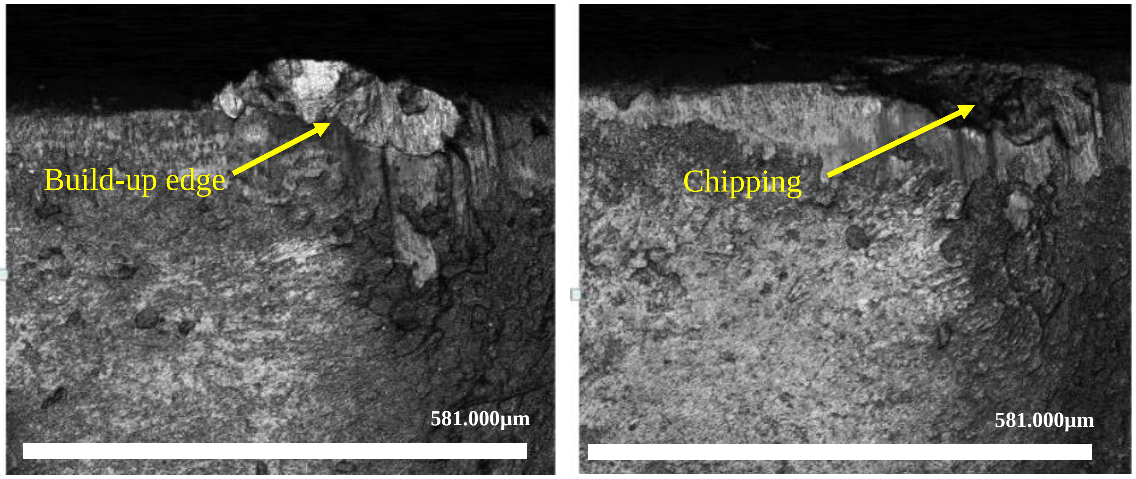


Figure 4: Surface topography in difference material rate volume.

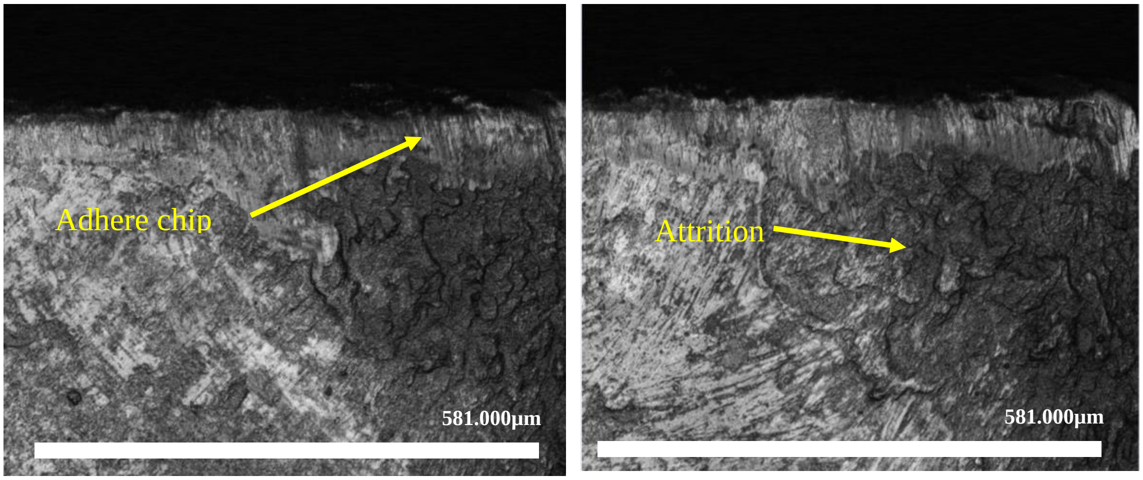
Figure 5 shows flank wear conditions of carbide chip breaker at two different experiments on feed rate and rake angle. Built-up edge occurs on the experiment 1 with lower feed rate of 0.2 mm/rev at cycle 4 of 138 × 10^5 mm^3. Besides, attrition is observed with dull surfaces at the tool–chip contact zone after cycle 5 of 172 × 10^5 mm^3. Abrasion and micro-abrasion marks are observed at the flank vicinity beside the attrition zone. Micro-abrasion is a result of broken abrasive metal pieces rubbing against the tool surface (Khrais, S. K., & Lin, Y. J., 2007). A combination of abrasion and attrition is attributed to a low feed rate of 0.2 mm/rev and rake angle of −6°, which produce continuous chip, as shown in Figure 6a.

In Figure 6, the shear stress generates rough abrasion, leaving abrasion marks on the outer surface followed by micro-abrasion marks near the boundary between the abrasion marks and coating delamination. Initial splitting of coated material led to a total peeling-off of the surface at 172 × 10^5 mm^3 of MRV at 5 cycles, which is always referred to as coating delamination. Damaged coating provides weak protection of tool surface underneath, as exhibited by dull surfaces to which the vicinity is significantly exposed for hard friction. Moreover, rapid attrition area at face flank face severe splitting of coated material may lead to the formation of flank wear with attrition at the vicinity of the flank edge. However, an effective feed rate of 0.4 mm/rev with −9 improved machining performance by reducing tool wear length and surface topography.



(a) Feed rate = 0.2 mm/rev and rake angle = -6° at MRV = 138×10^5 mm^3

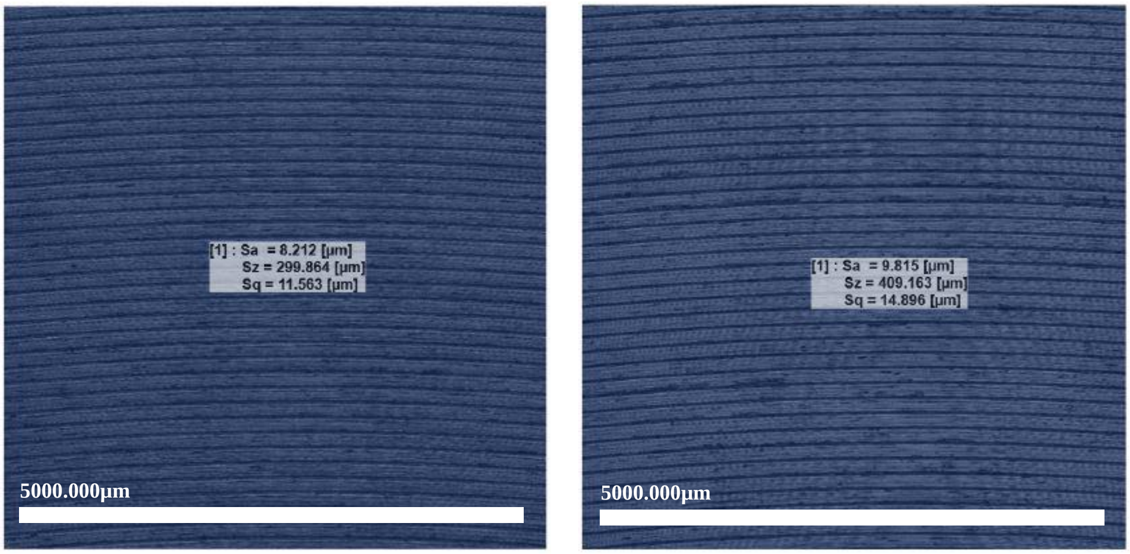
(b) Feed rate = 0.2 mm/rev and rake angle = -6° at MRV = 172×10^5 mm^3



(c) Feed rate = 0.4 mm/rev and rake angle = -9° at MRV = 138×10^5 mm^3

(d) Feed rate = 0.4 mm/rev and rake angle = -9° at MRV = 172×10^5 mm^3

Figure 5: Tool wear after continuous cutting at different MRV.



(a) Feed rate = 0.2 mm/rev and rake angle = −6° at MRV = 138×10^5 mm^3

(b) Feed rate = 0.2 mm/rev and rake angle = −6° at MRV = 172×10^5 mm^3

(c) Feed rate = 0.4 mm/rev and rake angle = −9° at MRV = 138×10^5 mm^3

(d) Feed rate = 0.4 mm/rev and rake angle = −9° at MRV = 172×10^5 mm^3

Figure 6: Surface topography measurement.

CONCLUSION

The objective of this experiment was to understand the effects of rake angle and feed rate on wear and surface topography in machining carbon steel 1045. The investigation has concluded the presence of a linear uniform wear rate and surface topography to the increment amount of material rate removal. The observations from this study suggest that increasing the rake angle from -6° to -9° and increasing the feed rate value to produce better chip and reduce machining time are possible. The effect of rake angle and feed rate overcome the problem of continuous chip that associated with low tool wear and surface topography. Future research needs to establish whether material rate volume is necessary to be increased to collect failure region data.

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