Effect of Rake Angle and Feed Rate on Chip Segmentation in Machining Carbon Steel 1050

M F Zamri* and A R Yusoff
Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, Malaysia
Corresponding author *: fawzizamri@gmail.com

Abstract. A chip breaker plays an essential role for chip breaking as well as to enhance productivity and quality during the turning process. However, chip break as a tool is not able to break the chip and formulate continuous chip, that in turn, causes the tool to wear and the generate excessive heat. These affect the quality of the machined surface. Chip formation is influenced by cutting conditions and tool geometries such as spindle speed, feed rate, depth of cut and rake angle. In this study, experiments were carried out on carbon steel 1050 with chip breaker at a constant cutting speed of 275 m/mm with a depth of cut 0.9 mm. The effect of different feed rate and rake angle towards chip length formation were also investigated in the present investigation. The results obtained from the study indicates that segmented chips could be obtained at a feed rate of 0.4 mm/rev and a rake angle of -9°. Therefore, it could be concluded that the feed rate and rake angle can play a significant role in the formation of the segmented chip through the use of a chip breaker to enhance the productivity and quality in the machining process.

1. Introduction
Machining can be considered as an essential process in manufacturing processes to manufacture high-quality products at low-cost production. One of the most important elements in machining is the tools, and the cost of each tool can vary according to their function as well as its endurance. A new cutting tool performance behaviour test could help businesses gain a competitive edge. Performance of machining process depends on the surface smoothness, and hence it becomes one of the major topics in process planning and machining optimization to increase the productivity of the product and lowering tooling cost. It has been reported in the literature that cutting process parameters such as depth of cut, feed and speed influence product quality [1].

Turning operation is one of the continuous metal cutting processes in which the form and size of chips are among the two factors that indicate the state of a cutting condition. Thus, development of an appropriate chip control method to achieve the desirable chip form concerning cutting force magnitude is necessary. Therefore, chip control plays an important role in metal cutting. Chip control is often governed by chip flow, chip curl, and chip breaking [2]. Moreover, uninterrupted chip flow is required in automated manufacturing systems to reduce human labour, process costs, and eventually to improve productivity in the production systems [3-4]. Rodriguez et al. investigated metal cutting simulation with a particular numerical technique, the Particle Finite Element Method (PFEM) with a new modified time integration algorithm and incorporating a contact algorithm capability. The goal is to reproduce the formation of segmented chip in orthogonal machining [5]. Then, Acuto et al. propose an analytical approach of modelling to determine the chip flow direction in bar turning [6].

[Image: This image contains the Creative Commons Attribution 3.0 licence notice.]

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Chip breaking is defined as breaking up the chip into a manageable size for a metal removal process where a segmented chip is being formed. In general, this is achieved by causing the chip to be formed into an approximately circular arc [7]. The authors in [8] performed an experimental work which deals with the influence of two design parameters, width and angle of the chip breaker. Mesquita and Barata studied on predicting cutting forces in machining of martensitic stainless steels using coated carbide tools [9]. The technique is based on the measurement of the chip-breaker geometry and the calculation of the effective side-rake angle. The performance of commercial chip breakers was evaluated using artificial neural network (ANN) that was trained through a back-propagation algorithm [10]. Essential independent variables such as depth of cut, land, breadth, and radius that directly influence the chip formation were used as input values of the ANN model. It was demonstrated that the ANN model is able to predict the chip formation well. Gurbuz et al. investigated the influence of different chip breaker geometries on cutting forces and tool stresses developed during turning [11]. Saigalik et al. deals with the elimination of long chip created when machining of a shaft used for the automotive industry [12]. The impact of chip-breaker’s shape on the shape of the chip in various cutting conditions based on production requirements were investigated.

Surface roughness is one of the key indicators of machining quality. Das et al. evaluate the performance of multilayer coated carbide inserts during dry turning of hardened AISI 4340 steel (47 HRC). The effect of machining parameters (depth of cut, feed and cutting speed) on surface roughness (Ra) was investigated by applying ANOVA [13]. Mesquita et al. studied on the effect of cutting speed on chip-breaking when using advanced carbide tooling with sintered chip-breakers [14]. Abbas et al. predicting the surface roughness for different cutting parameters in CNC turning operations by using ANN [15]. In the ultra-precision diamond cutting process, the rake angle of the tool becomes negative because the edge radius of the tool is considerably larger as compared to the sub-micrometre depth of the cut [16]. Puls et al. present an experimental test to analyze friction phenomena within the tool-chip interface in metal cutting. The experimental approach is derived from an orthogonal cutting process, modified to a high-speed forming and friction process by using an extremely negative rake angle [17]. One of the important characteristics of chip morphology is chip segmentation. Devotta et al. focused on the role of tool rake angle (α) on-chip segmentation [18]. A considerable amount of literature suggests that cutting speed and feed rate influences chip segmentation. Therefore, this study aims at investigating the effect of different rake angle and feed rate in the turning process by using a chip breaker towards chip formations.

2. Materials and Methods
The workpiece material used for this investigation is carbon steel 1050 (Fig. 1a). The axial length and the diameter of the cylindrical rod are 90 mm and 125 mm, respectively. The chemical composition of workpiece material is presented in Table 1 [19-22]. The cutting tool used for this study is a carbide insert with chip breaker (CNMG 120412 PM 4325) with Sanvick tool holder (DCLNR 2525M 12) depicted in Fig. 1b and Fig. 1c, respectively. The cutting speed and depth of cut for this project were set at a constant rate of 275 m/mm and 0.9 mm, accordingly. The specimen must be clamped tightly with dead centre during the cutting operation. 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 of was changed to 0.2, 0.3, 0.4 and 0.5 mm/rev. 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 as recommended by previous investigations [16-18]. Fig. 1d shows the parameters for rake angle which are -3°, -6°, -9°, and -12°, respectively. The original rake angle from tool holder DCLNR 2525M 12 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. The turning process was performed under flood cooling cutting conditions. The details of the tool holder and other cutting conditions are presented in Table 2.
Figure 1. (a) Carbon steel 1050 (b) Carbide insert with chip breaker (c) Tool holder (d) Rake angle

| Composition   | (Wt. %)   | Composition   | (Wt. %) |
|---------------|-----------|---------------|---------|
| Iron, Fe      | 98.46-98.92 | Sulfur, S     | ≤ 0.050 |
| Manganese, Mn | 0.60-0.90  | Phosphorous, P| ≤ 0.040 |
| Carbon, C     | 0.470-0.55 |               |         |

Table 2. Cutting conditions

| Cutting conditions   | Descriptions       |
|----------------------|--------------------|
| Workpieces           | Carbon steel 1050  |
| Cutting speed        | 275 m/mm           |
| Depth of cut         | 0.9 mm             |
| Feeds                | 0.2 – 0.5 mm/rev   |
| Cutting conditions   | Wet cutting        |
| Cutting tools        | CNMG 120412 PM 4325|
| Tool holder          | DCLNR 2525M 12     |
| Rake angle           | -3 °, -6 °, -9 °, -12 °, |
| Responses            | Chip length        |

3. Result and Discussion

The effect of cutting parameters and rake angle on the performance of coated carbide insert is discussed in this section. The chip length obtained from the experiment is present in Fig. 2 and Fig. 3 for varying feed rate and rake angle. The result shows that the chip length decreases with increasing the value of feed rate and rake angle. It could be seen from Fig. 2 that for all rake angles investigated, the chip length decreases along the increasing feed rate, however, a minor increase in the length is observed for the feed rate of 0.5 mm/rev. Nonetheless, it is worth noting that the increase is marginal, with an increase of 1.5
mm between the feed rate of 0.4 mm/rev and 0.5 mm/rev. In addition, it could also be seen that there is an abrupt increase in the chip length, in particular for the rake angle of -9° and a feed rate of 0.2 mm/rev. Based on the results obtained, it could be concluded that the optimum feed rate for this study is 0.4 mm/rev as it produces the shortest chip length amongst the feed rates regardless of the rake angle. Furthermore, from Table 3, it is evident that the shortest chip length amongst the rake angles evaluated at the optimum feed rate of 0.4 mm/rev is attainable at a rake angle of -9°. This is primarily due to the optimum contact between the chip and the chip breaker. Therefore, it could be concluded that the optimum rake angle and feed rate observed to produce the shortest chip length of carbon steel 1050 in the present investigation are -9° and 0.4 mm/rev, respectively.

**Table 3. Cutting conditions**

| Rake Angle (°) | Feed Rate (mm/rev) | Chip Length (mm) |
|----------------|---------------------|------------------|
| -3             | 0.2                 | 500.0            |
| -3             | 0.3                 | 35.0             |
| -3             | 0.4                 | 9.0              |
| -3             | 0.5                 | 10.5             |
| -6             | 0.2                 | 88.0             |
| -6             | 0.3                 | 18.0             |
| -6             | 0.4                 | 6.0              |
| -6             | 0.5                 | 9.5              |
| -9             | 0.2                 | 230.0            |
| -9             | 0.3                 | 8.0              |
| -9             | **0.4**             | **3.0**          |
| -12            | 0.2                 | 40.0             |
| -12            | 0.3                 | 4.5              |
| -12            | 0.4                 | 4.0              |
| -12            | 0.5                 | 8.0              |

**Figure 2.** Variation of chip length depending on feed rate
4. Conclusion
This study evaluated the effect of varying the rake angle as well as the feed rate towards the formation of carbon steel 1050 chip. It was demonstrated from the experimental investigation, that the optimum feed rate and rake angle observed for cutting the aforesaid material is 0.4mm/rev and -9°, respectively. It was shown that the selected parameters lead to efficient breaking and effective removal of chips. It is worth noting that the results obtained are based on flood cooling cutting conditions and are limited to this condition. A further investigation is necessary to evaluate the aforesaid cutting parameters at different machining conditions, i.e., dry and minimum quantity lubrication cutting conditions in ascertaining its ability for chip formation. Moreover, the effect of different types of chip breakers towards the formation of carbon steel 1050 chip along with the aforesaid parameters should be investigated.

Acknowledgement
The authors would like to acknowledge Universiti Malaysia Pahang for funding this project via PGRS 180321.

References
[1] Valera H Y and Bhavsar S N 2014 Experimental Investigation of Surface Roughness and Power Consumption in Turning Operation of EN 31 Alloy Steel Procedia Technology 14 528–534 https://doi.org/10.1016/j.proctey.2014.08.067
[2] Zhou L 2001 Machining Chip-Breaking Prediction with Grooved Inserts in Steel Turning Worcester Polytechnic Institute
[3] Pereira R B D, Braga D U, Nevez F O and Da Silva A S C 2013 Analysis of surface roughness and cutting force when turning AISI 1045 steel with grooved tools through Scott-Knott method International Journal of Advanced Manufacturing Technology 69(5–8) 1431–1441 https://doi.org/10.1007/s00170-013-5126-3
[4] Qibiao Y, Zhanqiang L and Bing W 2012 Characterization of chip formation during machining 1045 steel International Journal of Advanced Manufacturing Technology 63(9–12) 881–886 https://doi.org/10.1007/s00170-012-3954-1
[5] Rodriguez J M, Carbonell J M, Cante J C and Oliver J 2017 Continuous chip formation in metal cutting processes using the Particle Finite Element Method (PFEM) International Journal of Solids and Structures 120 81–102. https://doi.org/10.1016/j.ijsolstr.2017.04.030
[6] D’Acunto A, Le Coz G, Moufki A and Dudzinski D 2017 Effect of Cutting Edge Geometry on Chip Flow Direction-Analytical Modelling and Experimental Validation Procedia CIRP 58 353–357. https://doi.org/10.1016/j.procir.2017.03.327
[7] Worthington B 1976 The operation and performance of a groove-type chip forming device International Journal of Production Research 14(5) 529–558 https://doi.org/10.1080/00207547608956623
[8] Ali M and Murugan M 2009 Influence of chip breaker location and angle on chip form in turning low carbon steel International Journal Machinability of Materials 5(January 2009) 452–475 https://doi.org/10.1504/IJMMM.2009.026903
[9] Mesquita R M D and Marques M J M B 1992 Effect of chip-breaker geometries on cutting forces Journal of Materials Processing Technology 31 317–325
[10] Kim H, Sim J and Kweon H 2008 Performance evaluation of chip breaker utilizing neural network Journal of Materials Processing Technology 9 647–656 https://doi.org/10.1016/j.jmatprocess.2008.02.064
[11] Gurbuz H, Kurt A, Ciftci I and Seker U 2011 The Influence of Chip Breaker Geometry on Tool Stresses in Turning Journal of Mechanical Engineering 57 91–99
[12] Šajgalík M, Czán A, Martinček J, Varga D, Hemžský P and Pitela D 2015 The Impact Of Surface Shape Of Chip-Breaker On Machined Surface Technological Engineering XII(2) 4–7 https://doi.org/10.1515/teen-2015-0014

[13] Das S R, Kumar A, Dhupal D and Mohapatra S K 2013 Optimization of Surface Roughness in Hard Turning of AISI 4340 Steel using Coated Carbide Inserts International Journal of Information and Computation Technology 3(9) 871–880

[14] Mesquita R M D, Soares F A M and Marques M J M B 1996 An Experimental Study of The Effect of Cutting Speed On Chip Breaking Journal of Materials Processing Technology 56 313–320

[15] Abbas A T, Alata M, Ragab A E, Rayes M M El and Danaf E A El 2017 Prediction Model of Cutting Parameters for Turning High Strength Steel Grade-H : Comparative Study of Regression Model versus ANFIS Advances in Materials Science and Engineering 12

[16] Son S, Lim H and Ahn J 2006 The effect of vibration cutting on minimum cutting thickness International Journal of Machine Tools and Manufacture 46(15) 2066–2072 https://doi.org/10.1016/j.ijmachtools.2005.12.011

[17] Puls H, Klocke F and Lung D 2014 Experimental investigation on friction under metal cutting conditions Wear 310(1–2) 63–71 https://doi.org/10.1016/j.wear.2013.12.020

[18] Devotta A, Beno T, Siriki R, Lőf R and Eynian M 2017 Finite element modeling and validation of chip segmentation in machining of AISI 1045 steel Procedia CIRP 58 499–504 https://doi.org/10.1016/j.procir.2017.03.259

[19] Baday S, Basak H and Gural A 2016 Analysis of spheroidized AISI 1050 steel in terms of cutting forces and surface quality 315–320

[20] Baday S, Basak H and Sonmez F 2017 The Assessment of Cutting Force with Taguchi Design in Medium Carbon Steel – Applied Spheroidization Heat Treatment Measurement and Control 50(4) 89–96 https://doi.org/10.1177/0020294017713767

[21] Valera H Y and Bhavsar S N 2014 Experimental Investigation of Surface Roughness and Power Consumption in Turning Operation of EN 31 Alloy Steel Procedia Technology 14 528–534 https://doi.org/10.1016/j.protcy.2014.08.067

[22] Gürbüz H, Sözen A and Şeker U 2016 Modelling of Effects of Various Chip Breaker Forms on Surface Roughness in Turning Operations by Utilizing Artificial Neural Networks Journal of Polytechnic 19(1) 71–83