A Study of Chip Formation Feedrates of Various Steels in Low-Speed Milling Process

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Abstract. Milling is a process of metal removal by feeding the workpiece a rotating multitoothed cutter. The objective of the study was to investigate the chip characteristics (chip length, width, and thickness) during the milling process by varying the feedrates and the types of materials used based on an experimental approach. The chosen materials were AISI 1020, AISI 1045, AISI 1090, AISI D2, and AISI 4340 with a high-speed steel (HSS) as a cutter. In this work, the feedrates were varied of 5, 10, and 15 mm/minutes with the depth of cut of 0.5 mm and a low spindle speed of 70 rpm. The results show that, in general, increasing the feedrate will lead to the growth of chip length, width, and thickness for all types of materials used. Also, related to the chip shape, AISI 1020 produces the discontinuous chip which can be related to its hardness value.

Keywords: Chip formation, low speed, steel, milling, hardness

1. Introduction

One of the popular kinds of metal used in industry is steel. The use of steel is mostly for constructions and many tools. The progress of technology has produced the commercial steel. By determining the chip form from a conventional milling machine, it is believed that its mechanical properties can be determined. The research of chip characteristics has attracted many researchers from all over the world. Most of them used the cutting parameter with a high spindle speed. It is proven that the characteristic of chip varying the depth of cut and feedrates for different steels can affect the differences in chip dimension (width, length, and thickness) besides the differences in color (brown, blue, and green) [1].

Analyzing the character of chip formation can be done to control the quality of the material used. Therefore, the mechanical properties of a material can be approached. To analyze the chip, the variations of feedrates regarding low spindle speed and the depth of cut should be investigated. Then, the chips from each type of steel with a change of feedrates were observed by the perception of its formation and dimension.

In one of the previous works [2], the characteristic of the chip with face milling has ever been explored by using WCB (Wrought Carbon with grade B) varying the cutting parameters of feedrate and the depth of cut. In addition, the chip formation was also influenced by the cutting direction both in down and up milling processes [3]. Also, the formation of the chip could also be affected by the
differences of spindle speed with a large range of the speed [4]. Later, in [5] the chip characterization of titanium material of Ti-6Al was also investigated with the perception method of chip in a three-dimensional model and the micro-hardness measurement regarding the length and width of the chip [5].

By extending the published results with the main frame of the chip formation, this work aimed to investigate the feedrate effect on the chip formation in different types of steel materials experimentally. Also, the resulted chip shape was also investigated related to the prediction of the type of the material used.

2. Experimental Method
The experiment was performed by a conventional milling machine as shown in Figure 1. Various steels used in this study were AISI 1020, AISI 1045, AISI 1090, AISI D2 and AISI 4340 which have different hardness levels. The dimension of the workpiece was Ø50.8 x 60 mm. The cutting tool with end mill cutter was 10 mm in diameter.

In this work, the operating conditions of the feedrates were varied. A digital microscope was used to analyze the chip formation. The following are the details of the experimental setup:

(1) Spindle speed : 70 rpm
(2) Depth of cut : 0.5 mm
(3) Cooling : dry processes
(4) Feedrate : feedrate 1 (5 mm/min);
               feedrate 2 (10 mm/min);
               feedrate 3 (15 mm/min)

Figure 1. Milling process of various kinds of steel using a conventional milling machine

The use of the conventional milling machine with low spindle speed and without cooling in the process was purposed for getting chips since it offered an easy chip characterization. As seen in Figure 1, the cutting edge cut the workpiece, and small chips were produced over a very short period. Mostly, sliding frictions occurred between the tool and the workpiece. Chips were quickly generated on the rake face of the cutting edge to be then separated. Finally, the bending chips flowed out along the rake face, but there were still some small chips adhering to the cutting edge.

3. Results and Discussion
The chips from the machining test were collected, mounted, and measured. Figure 2 shows the chip formation with different steels and feedrates. It can be seen that the chip formation for all steel types
and feedrates was in the form of discontinuous chips. The chip geometry was relatively small, especially for the chip length (1.5 to 3 mm). From Figure 2, it is important to note that the chips for all feedrates and commercial steel types are in the form of Auto Reset Chips (ARC). There was an interesting result that AISI 1020, which has the lowest carbon content compared to others, tended to generate discontinuous chip for all feedrates considered in this work. It indicated that the AISI 1020 from the chip formation and in connection with the physical properties, showed a high hardness value. Note that the morphological size of the saw-tooth chip as a base of the chip formation measurement conducted in this work was described in detail [1].

In addition, from Figure 2, it can be observed that the serrations of the chip surface seemed to be neat for the feedrate values of 5 and 10 mm/min. While for a high feedrate, that is, 15 mm/min, the serrations tended to be irregular chips. Also, the chip resulted from high feedrate milling appeared to get small cracks (or called as chip breaks). Figures 3 to 5 show the effect of the feedrate on the chip length, width, and thickness, respectively, with varied types of steel materials. Based on Figure 3, it can be seen that the increasing the feedrate would increase the chip length. However, for AISI 1090 and AISI D2, there was a decrease in the chip length when the feedrate was 10 mm/min. Figure 4 demonstrates that the chip width was increased along with the improved feedrate. AISI 1020 had the largest chip width. A possible explanation was that AISI 1020 had the lowest carbon content which might resist to the applied force during milling. From Figure 4, it can be understood that the feedrate had a strong effect on the chip thickness, especially for AISI 4340. It was because AISI 4340 had the highest hardness level among others. One issue that was encountered during the experiment was that the feedrate had a strong correlation with the chip characteristics (chip length, width, and thickness) depending on the operating conditions.
Figure 2. Chip formation of various steels: (a) AISI 1020, (b) AISI 1045, (c) AISI 1090, (d) AISI D2, and (e) AISI 4340
Figure 3. The effect of feedrate on the chip length under different steels

Figure 4. The effect of feedrate on the chip width under different steels
Figure 5. The effect of feedrate on the chip thickness under different steels of PVP/ZnO

4. Conclusion
The effect of feedrates on a chip characteristics varying the steel materials (AISI 1020, AISI 1045, AISI 1090, AISI D2, and AISI 4340) has been successfully investigated. Based on the discussion, the following conclusion could be drawn. Increasing the feedrate will increase the chip length, width, and thickness for all types of materials used. The significant result of this study was that the chip formation could be considered as the guide to determine the hardness level of the materials.

5. References
[1] Wang C, Xie Y, Zheng L, Qin Z, Tang D and Song Y Research on the Chip Formation Mechanism during the high-speed milling of hardened steel Int. J. Mach. Tools Manuf 79 pp. 31–48, 2014.
[2] Sheth S and George P M Experimental Investigation and Prediction of Flatness and Surface Roughness during Face Milling Operation of WCB Material,” vol. 23, pp. 344–351, 2016.
[3] Wertheim R, Satran A and Ber A 1994 Modifications of the Cutting Edge Geometry and Chip Formation in Milling CIRP Ann. - Manuf. Technol. 43 no. 1 pp. 63–68
[4] Zhanqiang L and Guosheng S 2012 Characteristics of chip evolution with elevating cutting speed from low to very high,” Int. J. Mach. Tools Manuf., vol. 54–55, pp. 82–85
[5] Sun and Guo Y B A new multi-view approach to characterize 3D chip morphology and properties in end milling titanium Ti-6Al-4V Int. J. Mach. Tools Manuf 48 no. 12–13, pp. 1486–1494, 2008.

Acknowledgements
The authors would like to express their gratitude to the Laboratory of Physical Metallurgy, Diponegoro University, for the experiment. The authors would also like to appreciate the useful comments and suggestions from reviewers.