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Performance of milling mold steel on surface roughness and tool wear characteristics

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ABSTRACT
The objectives of this research effort were to study and compare cutting surface quality and the effects of AISI-P20 tool steel to AISI-1050 tool steel. The milling machining process was set to various parameter values according to the following test conditions: feed rates of 45, 50 and 55 mm/min, spindle speeds of 510, 572 and 637 rpm, and milling ranges of 3, 5 and 10 mm, respectively, using 10-mm-diameter two-end mill cutting. Findings indicated that the tool steel with the best surface quality was the AISI-1050, which had the lowest roughness at 2.120. The most suitable parameter values for the best surface quality of both tools were the feed rate of 45 mm/min, spindle speed of 637 rpm and cutting range of 3 mm. Under all test conditions, the surface quality and end mill wear were directly impacted by the change of parameter values.

Keywords *- Plastic mold, Roughness, Milling, End mill, Tool wear*

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I. INTRODUCTION

Currently, the mold industry is a key part of the production process that enables rapid and continuous development, particularly in mass production [1]. It is believed that the mold material plays a significant role in producing sufficient product quality. Therefore, in order to reduce the probability of defects of the finished product and prolong the useful life of the mold, the surface quality was compared to the types of tool steel and cutting parameters. These parameters affected the roughness of tool steel and the ability to produce the mold from different tools based on the type of milling machining part. The goal is to increase the quantity and quality of the mold product to be competitive [2, 3].

Surface finish is the most important factor to consider in order to produce high quality molds, but the effect of tool operation and quality is not well-understood. Therefore, various tool operating factors were studied to determine their effect on surface finish including [3] spindle speed, feed rate, cutting speed, and tool type [4]. Additionally, merely controlling the operating parameter values is not sufficient because end mill wear is considered a key factor that affects the quality of the work piece.

Therefore, cutting efficiency and surface smoothness of AISI-P20 and AISI-1050 tool steel were examined by changing the feed method and feed rate and examining the 10-mm-diameter two-end mill carbide wear. After cutting, the obtained data are planned to be used in the mold manufacturing industry for the highest efficiency.

II. EXPERIMENTAL PROCEDURE

Materials and Equipment

Table 1 Physical Properties of Work Piece Machine [5]

Properties	AISI-P20	AISI-1050
Tensile Strength (MPa)	1,290	690
Yield Strength (MPa)	1,035	580
Elastic Modulus (GPa)	190-210	190-210
Density (g/cm^3)	7.81	7.85
Hardness (HRC)	42	22
Chemical Composition (%)	C : 0.4%, Mn : 1.5%, Cr : 1.9%, Mo : 0.2% Other	C : 0.47-0.53%, Si : 0.15-0.35%, Mn : 0.60-0.90% Other

The tools used in this experiment were the tool steel grade AISI-P20 and AISI-1050, which are favored in the mold industry and suitable for machining in terms of surface quality and durability. Both tool steel types are qualified as presented in Table 1. The cutting tool was an end mill carbide OMER HSS-AL GROUND END MILLS DIN844 2F 10 x 10 x 22 x72 mm [5] used for machining.

The machine used in the CNC Milling test was the CHEVALIER 2040 VMC with three-cores controlled by a computer. Surface quality was assessed by a surface roughness tester, MahrMarSurf PS1 to determine the surface roughness (Ra) after the cutting process under all conditions at an 8-mm range. A stereo microscope Leica EZ 4D model and Scanning Electron Microscope (SEM) were used to analyze the surface. Furthermore, a Scanning Probe Microscope tester was also applied with Atomic Force Microscopy (AFM) to measure the 20 x 20 µm work piece.

Process

The size of the testing work pieces of AISI-P20 and AISI-1050 tool steel were determined by their suitability for the capture of the milling machine and the analytical measurement tool which is 50 x 50 x 50 mm. The test was conducted with feed rates of 45, 50 and 55 mm/min, spindle speeds of 510, 572 and 637 rpm, and cutting ranges of 3, 5 and 10 mm according to the standard and other conditions, as outlined in Table 2. The work piece from the cutting process is presented in Figure 1. Afterward, the surface roughness of the work piece (Ra) was examined with the surface roughness tester, the quality of the surface and chip was examined with the stereo microscope, and finally, the cutter wear was examined with the SEM.

Table 2 Experimental Conditions. [1, 6]

Experiments Conditions	Descriptions	
Materials Workpiece	AISI-P20	AISI-1050
Spindle Speed (rpm)	510, 572, 637	
Feed per tooth (mm/tooth)	0.0353 – 0.0539	
Feed Rate (mm/min)	45, 50, 55	
Area of Cut (%)	100	
Depth of Cut (mm)	1	
Level Depth of Cut (mm)	3, 5, 10	
Cutter	OMER HSS-AL GROUND END MILLS DIN844 2F Size 10x10x22x72 mm	
Milling Machine	CNC CHEVALIER Model 2040VMC	
Milling Direction	Down-out	
Cooling	Soluble oil	

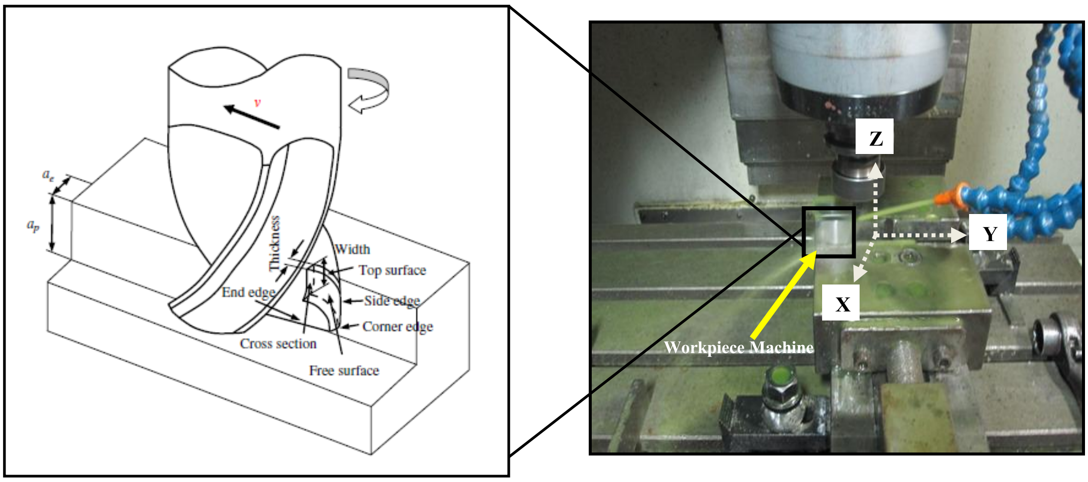
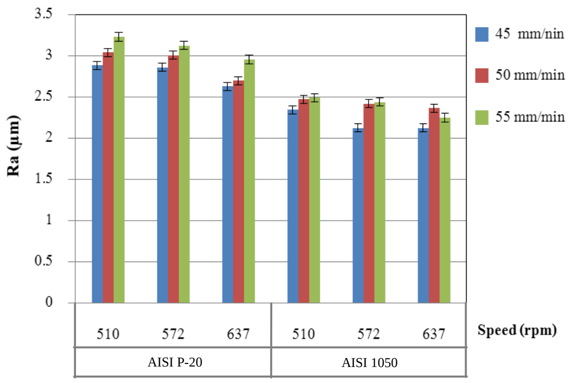


Fig. 1 The cutting process's characteristics

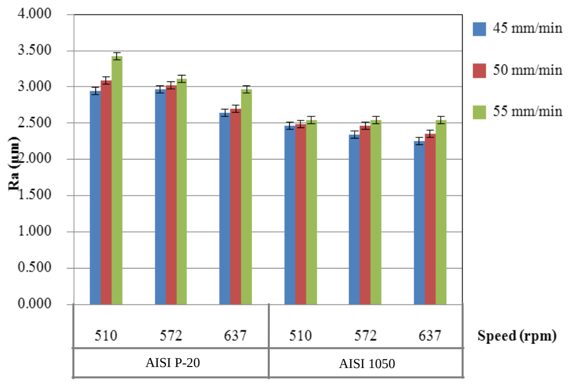
III. RESULTS AND DISCUSSION

Surface roughness (Ra)

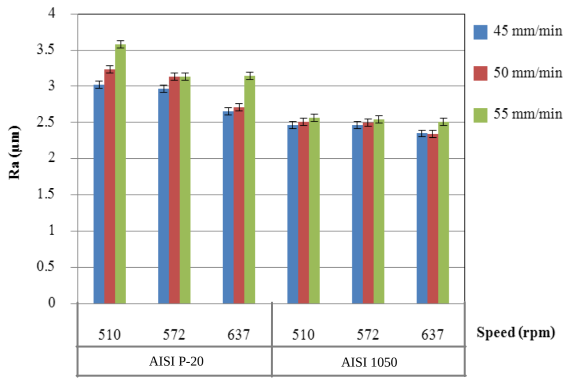
The test aimed to find the suitable parameter value for the milling machining process of both tool steels and to compare the surface roughness (Ra) for each parameter of feed rate, spindle speed, and cutting range. Results showing the average roughness value of cutting work with AISI-P20 and AISI-1050 are presented in Figure 2. When cutting with feed rates of 45, 50 and 55 mm/min, spindle speeds of 510, 572 and 637 rpm and cutting ranges of 3, 5 and 10 mm, the results demonstrate that the roughness (Ra) increased and decreased dramatically due to the different feed rates, spindle speeds, and cutting ranges of both tool steels. The results show that the average surface roughness value (Ra) of AISI-P20 tool steel under all conditions was higher than that of AISI-1050 tool steel. The surface roughness value (Ra) had increased when the feed rate increased from 45, 50 and 55 mm/min. When the spindle speed increased from 410 rpm to 572 and 637 rpm, respectively, the roughness (Ra) appeared to continuously decrease under all conditions for both tool steels and at the three cutting ranges. This result implies that with a low feed rate and high spindle speed, the cutting rate of the milling cutter is less than the cutting rate of a milling cutter with a high feed rate and low spindle speed. This finding was observed because the low feed rate gradually cut the material and took more time with the high spindle speed. This resulted in good surface quality with a low roughness value (Ra). However, under the conditions of a high cutting rate and lower milling time, the surface quality was low due to the high feed rate and low spindle speed. Furthermore, the increased cutting rate affected the milling time, causing the cutting edge to wear out and impact the surface roughness value (Ra).



a) Level depth of cut 3 mm



b) Level depth of cut 5 mm



c) Level depth of cut 10 mm

Fig. 2 Arithmetic average roughness (Ra) provided

The surface roughness values were observed across all test conditions and presented in Figure 2 a) b) and c). It was found that the feed rate of 45 mm/min, spindle speed of 637 rpm, and milling range of 3 mm provided the best surface roughness values for both types of tool steel; Ra 2.120 µm for AISI-1050 and Ra 2.627 µm for AISI-P20. The highest Ra of both tool steels, which indicated low cutting quality, were 2.560 µm for AISI-1050 and 3.580 µm for AISI-P20 when tested with feed rate of 55 mm/min, spindle speed of 510 rpm, and cutting range of 10 mm [6].

Milling surface quality analysis

After examining the surface roughness of the work piece obtained from the milling machining process to identify the suitable parameter value of each tool steel, it was found that spindle speed, feed rate, milling range, and other conditions had an influence on surface texture and different surface roughness values. The textures were slightly different, while the roughness values depended on various factors. Therefore, work pieces with good quality surface texture and those with low-quality surface texture were analyzed with SEM 200x magnification to examine the cutting surface of both tool steels, as explained in Figure 3.

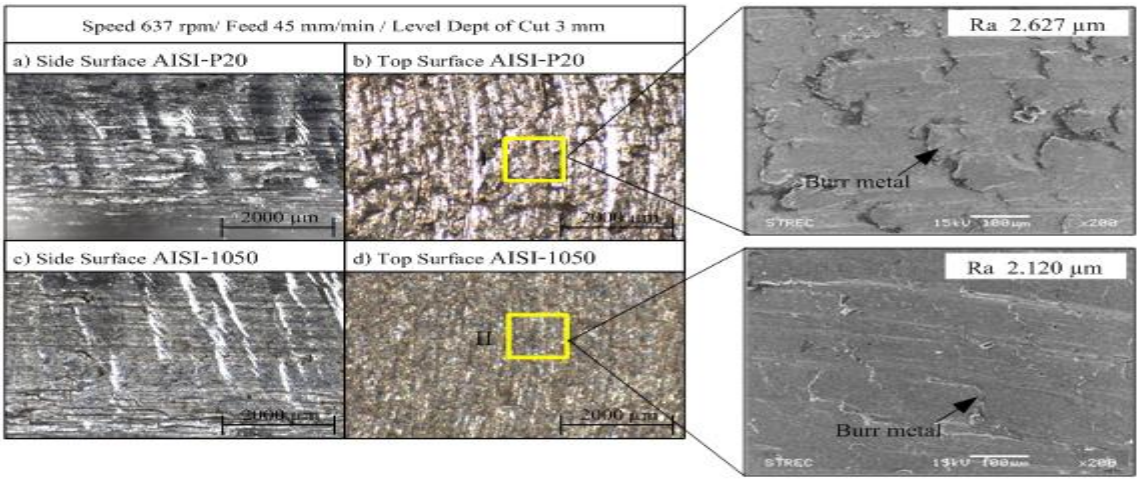


Fig. 3 SEM magnified 200x of the good surface quality for milling surface

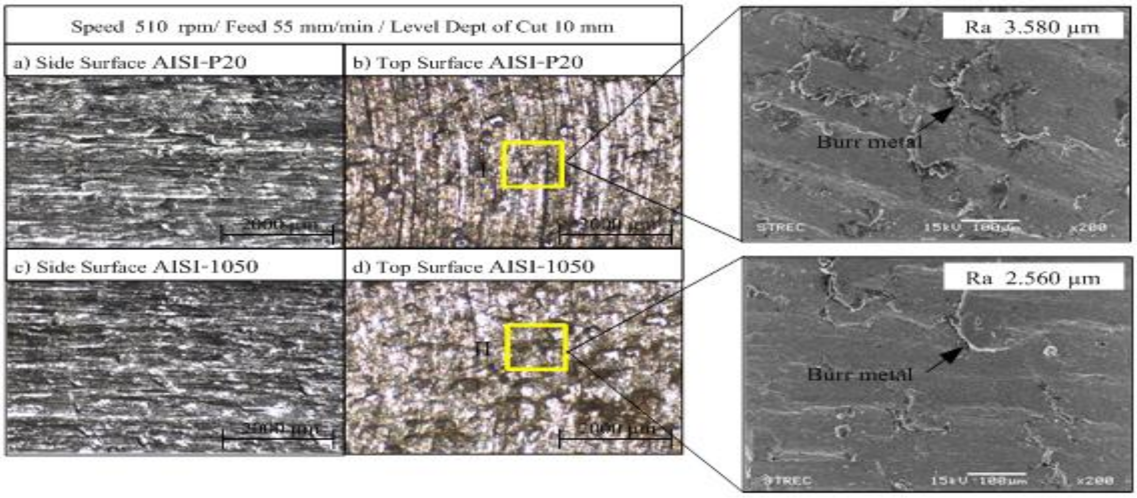


Fig. 4 SEM magnified 200x of the poor surface quality for milling surface

This examination showed that the front and side cutting had the best surface quality and the lowest surface roughness value. When tested with a feed rate of 45 mm/min, spindle speed of 637 rpm, and milling range of 3 mm with both tool steels, as exhibited in Figure 3 a) and b), it revealed that the side and front milling surface of both tool steels were obviously different. This result was due to the side surface being cut with a helix end mill cutting edge, which was different from cutting with an end mill surface. This finding was the reason for the wave on the side surface [7],as outlined in Figure 3 a) and c). However, the surface quality depended on the depth of cut on the material such that the side surface had slightly different texture. AISI-1050 tool steel had better quality of the side surface than those of AISI-P20. The front surface was the curved line which followed the rotation of the cutting edge resulting in the constant rough surface as showed in Figure 3 d). The surface of AISI-1050 tool steel was smoother than that of AISI-P20 tool steel (Figure 3 b)). When the surface was tested with the SEM at position I and II for both tools, it was found that the sliding metal from the cutting edge was the cause of surface irregularity [8], or Burr metal, which most likely happened to the surface of AISI-P20 tool, steel rather than to the surface of AISI-1050 tool steel.

Figure 4 presented the side and the front surface that had the lowest quality or that had the highest surface roughness value. When cutting with spindle speed of 510 rpm, feed rate of 55 mm/min, and cutting range of 10 mm, it was observed that the side and front surface of both tool steels were clearly different. However, because the side and the front surface of both tools were not different, the quality of the side and front surface of both tools were tested under the condition that caused the low surface quality. Deep irregularities were found on the surface and when examined with SEM on position I and II of both tool steels, it was found that there were significant amounts of Burr metal. These results were consistent with the surface roughness value obtained from the previous analysis [7, 8].

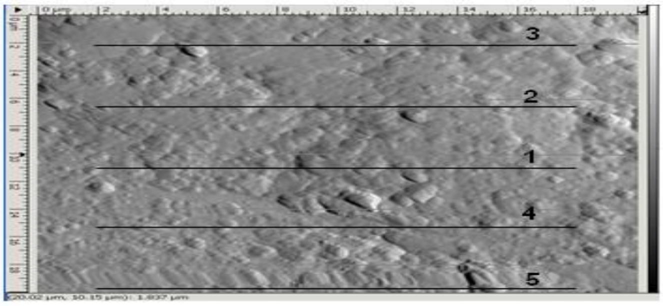
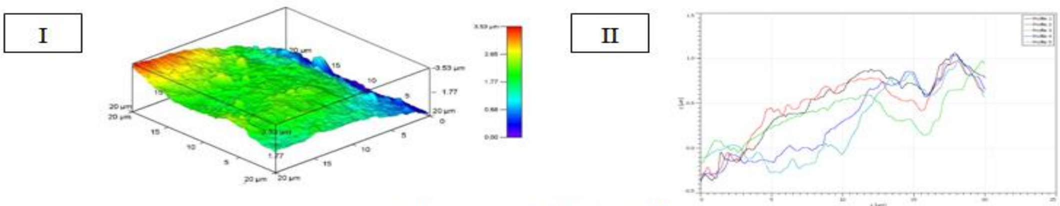
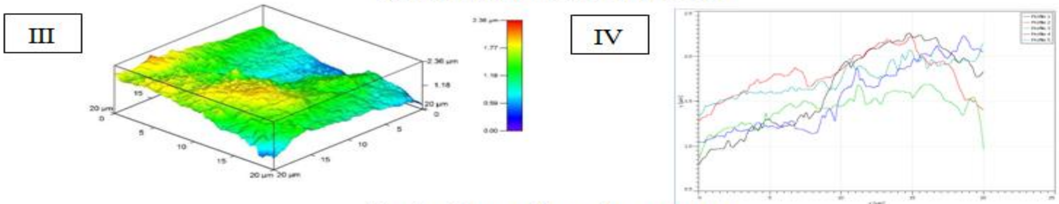


Fig. 5 Measured positions on the surface

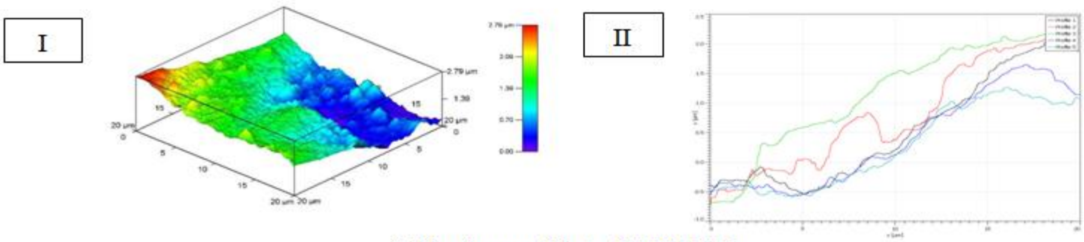


a) Plastic mould steel AISI-P20

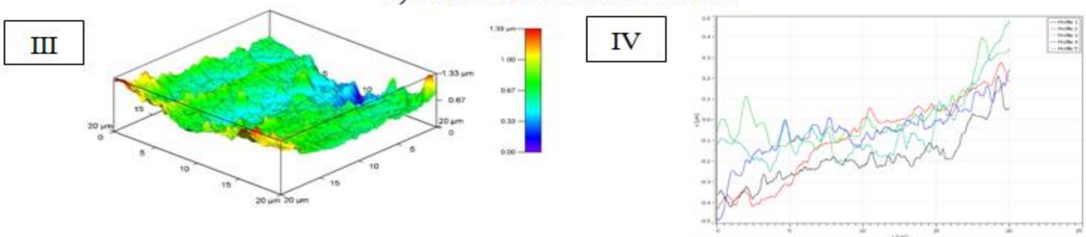


b) Plastic mould steel AISI-1050

Fig. 6 Characteristic of the good surface quality measured by AFM



a) Plastic mould steel AISI-P20



b) Plastic mould steel AISI-1050

Fig. 7 Characteristic of the poor surface quality measured by AFM

From the study on surface texture with SEM, the cause affecting the cutting surface quality and surface roughness values was discovered. Therefore, the cutting surface was measured with the Atomic Force Microscopy (AFM) technique. Figures 5, 6 and 7 show the measured positions, the best surface texture, and the worst surface texture, respectively. After testing AISI-P20 and AISI 1050 tool steels with various conditions and factors, it was found that the good surface texture, or the surface with lowest surface roughness values, had the constant low, plain curve texture. It was noticeable from the increasing graph line on the surface at the measuring positions as shown in Figure 6 a) and b) that good surface quality was achieved for AISI-P20 and AISI 1050 tool steels. When comparing the surface texture that had the highest surface roughness value, it was determined that the rough surface had rugged large holes and significant variance of depth levels, as outlined in Figure 7 a) and b). It could be observed that the graph line at the measuring position was inconsistent and tended to increase in a similar manner to the picture of the measuring cutting surface. This finding was the reason why the cutting surface had high surface roughness value [9, 10]. The result was consistent with the cutting surface quality analysis applying the SEM technique.

Chip analysis

Study of the chips after the cutting process of the two tool steels indicated that the chip texture was slightly different when testing at similar parameter values. Thus, chip texture was analyzed with the factors that had the most and the least effect to the surface roughness value. Results showed that the parameter values that gave the best surface cutting, or the lowest surface roughness value, were the feed rate of 45 mm/min, spindle speed of 637 rpm, and cutting range of 3 mm. Meanwhile, the parameter values that gave the worst surface cutting, or the highest surface roughness value, were the feed rate of 55 mm/min, spindle speed of 510 rpm, and cutting range of 10 mm. Chip texture from both tool steels after the test is described below.

Figure 8 a) and b) show that the chips had different texture after testing the same tool with different parameter values. Cutting with the feed rate of 45 mm/min and spindle speed of 510 rpm resulted in a loose and large helix shape. The end of the chip consisted of a helix angle and zigzag tears. Conversely, after cutting with the high feed rate and low spindle speed, the end of the chip was rather disjointed, straight and solid. Figure 8 c) and d) describes the chip texture of AISI-1050 tool steel and it was found that the chip cut with the same parameter value as AISI-P20 tool steel had a different texture. When testing with a feed rate of 45 mm/min and spindle speed of 637 rpm, the chip consisted of a tight helix in a smaller size compared to those cut with a feed rate at 55 mm/min and spindle rate at 510 rpm. The latter chip, however, was a similar size to the chip obtained from the AISI-P20 (Figure 8 a)) but was smaller than those from the AISI-P20 (Figure 8 b)), as explained earlier as the chip of solid material [11,12].

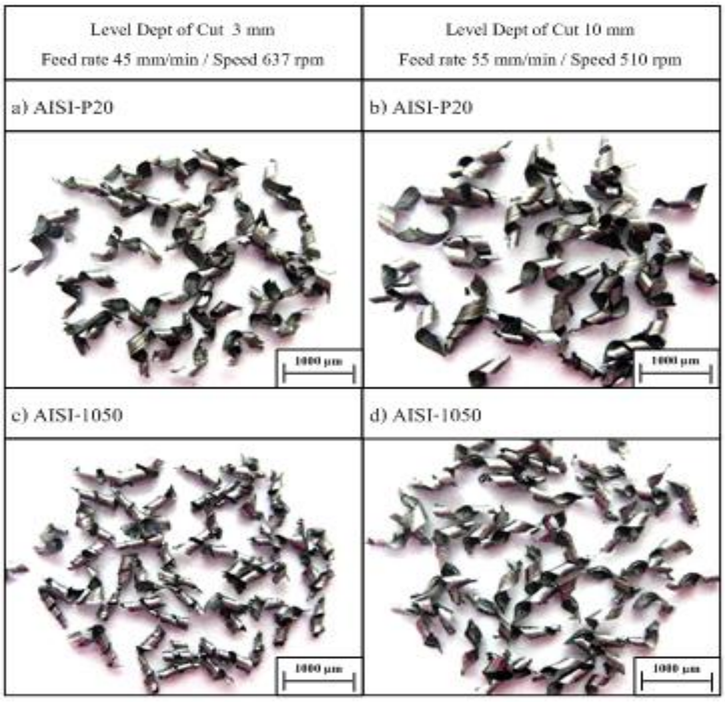


Fig. 8 Characteristic of machined chip of plastic mold steel AISI-P20 and AISI-1050

Wear analysis of end mill

The result of the cutting surface analysis with the two-end mill carbide tools showed that the factors affecting surface quality were spindle speed, feed rate, and cutting range. Particularly, the cutting range was the key variable to identify the cutting time of the end mill and its operational lifetime. Therefore, the end mill wear was studied after testing the conditions that had the least and most effects on surface quality. SEM was used to test the end mill that had a direct effect on the cutting as shown in Figure 9.

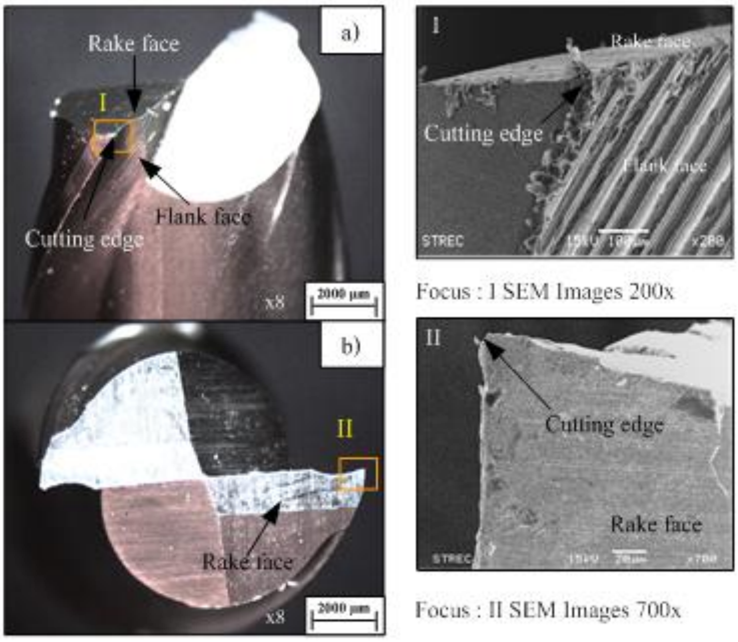


Fig. 9 Measured positions on cutting edge wear

It was found that the wear of the end mill happened when the spindle speed and feed rate had increased which affected the wear of the cutting edge in different ways. Examining the cutting edge after testing showed that the end mill had the least wear of its cutting edge and cutting angle when used with a feed rate of 45 mm/min, spindle rate of 637 rpm, and cutting range of 3 mm, as presented in Figure 10 and 11. The results showed the end mill, which cut AISI-P20 and AISI-1050 tool steel, wearing out. Moreover, using SEM 300x magnification to examine the cutting edge revealed that the wear occurred with all sides of the cutting edge: Rake face, Flank face, and side cutting edge. The wear was mostly found on the cutting edge which is called cutting edge wear. The wear was also found to be deep on the side cutting edge, rake face, and flank face, which is called side cutting edge wear, rake wear, and flank wear, respectively. This effect is shown in Figure 10 b) and d) and can be compared to Figure 10 a) and c), respectively. The side cutting edge that was magnified at 120x was found to have less cutting edge wear. When the side surface was magnified at 700x on position I and II, it was found that the wear was crucial because they were the areas which were directly affected by the end mill angle and cutting [13].

Figure 11 shows the end mill wear after the cutting test that had the most effect on the surface roughness values or caused the low surface quality. When cutting with a feed rate at 55 mm/min, spindle speed at 510 rpm, and cutting range at 10 mm, the rake wear had the round cutting edge. Upon examination, all of the cutting edges were affected by the cutting of both tool steels, as showed in Figure 11 b) and d). It was found that there were only a small number of rake wear and flake wear occurrences, while there was significant cutting edge wear, which was deep in the side cutting edge. Therefore, the overall wear of the end mill occurred on the cutting edge, which is called cutting edge wear. This result implies that the end mill, which cut the tool with the high feed rate, low cutting speed, and cutting range at 10 mm, would cause the round wear on the cutting edge in a wide area and would also cause the deep wear of the rake face and side cutting edge. Additionally, the depth had decreased based on the contact area with the cutting edge and material [14].

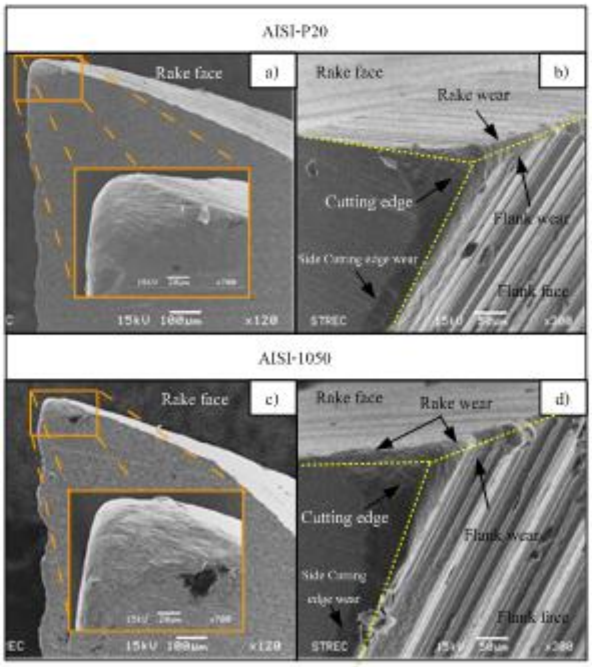


Fig. 10 Characteristic of less cutting edge wear

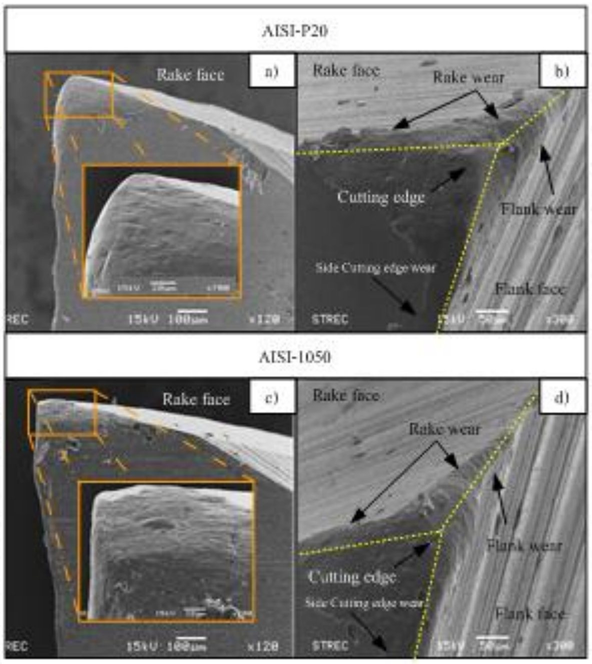


Fig. 11 Characteristic of lot cutting edge wear

Therefore, from the analysis of the end mill wear, it was found that the end mill cutting edge did not wear out quickly when cutting AISI-1050 tool steel with a feed rate at 45 mm/min, spindle speed at 637 rpm, and cutting range at 3 mm. The end mill that had the most wear was the one that cut with a feed rate at 55 mm/min, spindle speed at 510 rpm, and cutting range at 10 mm. AISI-P20 tool steel was cut because of the cutting rate of the cutting edge and the different operational life of the end mill. Moreover, the steel depended on the quality of material used in testing. This test result was similar and consistent with the research of S. N.B Oliaei et. al. [15] and Szymon Wojciechowski et. al. [16], as mentioned

IV. CONCLUSIONS

This study was conducted to determine the suitable parameter values for milling machining processes of AISI-P20 and AISI-1050 tool steel and to compare the effect on surface quality and tool wear under each test. The findings could be concluded as follows:

1) The most suitable parameter value which caused the lowest surface roughness value (Ra) of both AISI-P20 and AISI-1050 tool steel was the feed rate of 45 mm/min, spindle rate of 637 rpm, and cutting range of 3 mm. The AISI-1050 tool steel had the lowest surface roughness value of 2.120 µm.

2) Quality of the front and side surface were different depended on the cutting of each side cutting edge. The obtained surface quality was consistent with the surface roughness (Ra) that was affected by the parameter value of each condition.

3) Chips obtained from AISI-P20 and AISI-1050 tool steel were different based on cutting rate and quality of tool.

4) Cutting rate and cutting time of the end mill affected the wear of all sides of the cutting edge. When cutting with the low feed rate, high spindle speed, and low cutting range, there was less wear, resulting in low surface roughness (Ra) and good surface quality.

V. ACKNOWLEDGMENTS

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REFERENCES

[1] G. Kiswanto, D.L. Zariatin, T.J. Ko. The effect of spindle speed, feed-rate and machining time to the surface roughness and burr formation of Aluminum Alloy 1100 in micro-milling operation. Journal of Manufacturing Processes 16, (2014), pp.435-450.

[2] Paramet Baowan and Charnnarong Saikaew. Quality development and improvement in mold making industry with designed experiments. KKU Reserch Journal (GS) 13 (2) : April-June, (2013), pp.42 Times New Roman 53.

[3] Terdsak Arlai, Pongpan Kaewtatip and Kusol Prommul. influences of various working parameters in routing process of rubber wood using tungsten-carbide routers. The 17th Conference of the Mechaical Engineering Network, (2010), Thailand.

[4] Banleng Sornil and Prasert Guaysomboon. Tabellenbuch Metall. Bangkok; King Mongkut's Institute of Technology North Bangkok, (1974), Thailand.

[5] G.G. Ye, S.F. Xue, W. Ma, M.Q. Jiang, Z. Ling, X.H. Tong, L.H. Dai. Cutting AISI 1045 steel at very high speeds. International Journal of Machine Tools & Manufacture 56, (2012), pp.1-9.

[6] Sanya Kumjing, Chalerm Khun-eiad and Sinmahut Failui. Study of the qualification end mill by reverse engineering. Department of Industrial Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Suvarnapbumi, Nonthaburi, (2008), Thailand.

[7] J. Vivancos, C.J. Luis, J.A. Ortiz and H.A. Gonz´alez. Analysis of factors affecting the high-speed side milling of hardened die steels. Journal of Materials Processing Technology 162-163, (2005), pp.696-701.

[8] Cevdet Gologlu, Nazim Sakarya. The effects of cutter path strategies on surface roughness of pocket milling of 1.2738 steel based on taguchi method. journal of materials processing technology 206, (2008), pp.7-15.

[9] Sonja Jozić, Dražen Bajić, Luka Celent. Application of compressed cold air cooling: achieving multiple performance characteristics in end milling process. Journal of Cleaner Production 100, (2015), pp.325-332.

[10] Youngseok Oh, Jaeboong Choi, Youngjin Kim, Kyungsuk Kimc and Seunghyun Baik. The effects of ball milling process on the diameter dependent fracture of single walled carbon nanotubes. Scripta Materialia 56, (2007), pp.741-744.

[11] Chengyong Wang, Yingxing Xie, Lijuan Zheng, Zhe Qin, Dewen Tang, Yuexian Song. Research on the Chip Formation Mechanism during the high-speed milling of hardened steel. International Journal of Machine Tools & Manufacture 79, (2014), pp.31–48.

[12] Thanongsak Thepsonthi, Tuğrul özel. 3-D finite element process simulation of micro-end milling Ti-6Al-4V titanium alloy: Experimental validations on chip flow and tool wear. Journal of Materials Processing Technology 221, (2015), pp.128-145.

[13] W.Y.H. Liew and X. Ding. Wear progression of carbide tool in low-speed end milling of stainless steel. Wear 265, (2008), pp.155-166.

[14] A.Aramcharoen, P.T. Mativenga, S. Yang, K.E. Cooke and D.G. Teer. Evaluation and selection of hard coatings for micro milling of hardened tool steel. International Journal of Machine Tools & Manufacture 48, (2008), pp.1578-1584.

[15] S. N.B Oliaei, Y. Karpat. Experimental Investigations on Micro Milling of Stavax Stainless Steel. 6th CIRP International Conference on High Performance Cutting, HPC 2014, Procedia CIRP 14, (2014), pp.377-382.

[16] Szymon Wojciechowski, Pawel Twardowski. Tool life and process dynamics in high speed ball end milling of hardened steel. 5th CIRP Conference on High, Procedia CIRP1, (2012), pp.289 – 294.