Jurnal Tribologi 33 (2022) 125-136

Jurnal Tribologi
Website : jurnaltribologi.mytribos.org e-issn: 2289-7232

Optimization study on width of cut and cutting-edge radius during side milling of DAC 55 steel

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KEYWORDS

Cutting-edge radius (CER)
Width of cut
Surface roughness (Ra)
Tool wear
Milling machining

ABSTRACT

The surface roughness of machined surfaces, for example, plays a crucial role in the production of the final part or product. As a result, selecting the machining parameters and cutting tool geometry during machining is critical in determining tool wear progression as well as obtaining lower surface roughness or high surface quality of the surface after machining. The goal of this article is to optimize the cutting tool's cutting-edge radius (CER) of uncoated carbide and width of cut during the machining of DAC 55 steel. A continuous cutting speed of 2800 RPM and a feed rate of 350 mm/min were used to side mill DAC 55 steel. The influence of both factors on surface roughness and tool wear was studied using width of cut 0.1, 0.6, and 1.2 mm with CER of 10, 20, and 30 µm. The Full Factorial approach was used to assess the impact of combining cutting parameters. According to the findings, the width of cut has the greatest impact on enhancing surface quality compared to CER. It was discovered that using 30 µm CER and 0.1 mm width of cut resulted in the best surface finish quality. In terms of cutting tool wear, it was discovered that a cutting tool edge radius of 30 µm and width of cut of 0.1 mm experienced less wear when reaching a distance of 4400 mm.

Received 2 December 2021; received in revised form 13 February 2022; accepted 8 May 2022.
To cite this article: Tomadi et al. (2022). Optimization study on width of cut and cutting-edge radius during side milling of DAC 55 Steel. Jurnal Tribologi 33, pp.125-136.

1.0 INTRODUCTION

Surface roughness is one of the surface quality measurements frequently being measured and observed in producing any parts or components especially in the manufacturing and industrial application. As a result, the surface quality of machined surface material is critical to ensuring that the quality of product produced meets the expectations of consumers and clients. Surface roughness is classified into three types: arithmetical mean roughness (Ra), ten-point mean roughness (Rz) and maximum height (Ry). In determining the surface roughness of each part or product, arithmetic mean roughness (Ra) has always been selected above the other two kinds of measurement. A high value of surface roughness is frequently caused by machining settings that are not appropriately suitable to the type of machined material and cutting tool. Cutting speed, axial depth of cut, and feed rate, as well as cutting-edge radius (CER) and width of cut, all play a significant role in generating minimal surface roughness of machined material while having less tool wear.

Several studies have been conducted to evaluate the effect of cutting-edge radius (CER) and width of cut on surface roughness and tool wear. Yue et al. (2017) studied the effect of rounded shape cutting-edges on the surface roughness during machining of MgAl2O4 spinel ceramic. They discovered that the radius of the tool's cutting-edge (diamond), cutting speed, and feed rate are all affected by the quality of the surface after machining of MgAl2O4 spinel. Brown and Schoop (2020) investigated the impact of the cutting-edge and nose radius towards surface roughness while milling Titanium alloy Ti6A14V with uncoated carbide. They experimented with various cutting-edge radiuses (5, 35, 50, and 40:20 μm) and discovered that machining with a lower chip thickness results in a better machined surface. The bigger the cutting-edge radius, the thinner the chip generated. This is due to material displacement under and around the tool rather than into the chip. Shah and Bhavsar (2020) examined the influence of cutting speed, feed rate, depth of cut, and tool nose radius on surface roughness during Ti-6Al-4V machining (ELI). The cutting tool's nose radius (0.4, 0.8, and 1.2 mm) was studied. They discovered that a cutting speed of 140 rpm, a feed of 0.0510 mm/rev, a depth of cut of 0.7 mm, and a nose radius of 1.2 mm resulted in a lower value surface roughness. It demonstrates that the cutting-edge radius or nose radius has a substantial control on the surface roughness of the material, particularly the high hardness of the material.

Other researchers looked at the impact of cutting-edge radius (5, 10, and 15 μm) on surface roughness and tool life in ferrite – martensite steel (Fulemova & Janda, 2014). During the milling machining experiment, they discovered that the cutting-edge radius of 15 μm produced an excellent surface quality of machined material when compared to 5 and 10 μm. It demonstrates that higher cutting-edge radius during machining is more stable and efficient. They also discovered that when the cutting-edge radius is increasing, the cutting tool experienced decreased tool wear.

Surface roughness was controlled by cutting-edge radius (CER) and tool wear, and the findings clearly demonstrated that a large cutting-edge radius may generate lower surface roughness while increasing tool wear (Chou & Song, 2004). Other outputs such as chip formation, least chip thickness, tool wear, cutting pressures, and tool life are also affected by cutting-edge radius (Zhao et al., 2017).

Cutting factors such as cutting-edge radius and width of cut have constantly been studied in order to reduce surface roughness during machining. There are numerous methods for optimizing machining settings. Aside from simulation and manual research, design of experiment (DOE) is one of the popular methods. Paturi et al. (2020) used Full Factorial and Response Surface

Methodology (RSM) to optimize surface roughness or surface quality and tool wear during dry machining of AISI 52100 steel. They investigated and assessed the correlation between machining parameters and surface roughness and tool wear and discovered that the DOE technique was quite beneficial in improving machining parameters. Singh et al. (2020) investigated the effect of machining towards surface roughness of the machined material and material removal rate of AISI H11 steel after milling machining process. They used DOE, Taguchi technique and grey relational analysis (GRA) to find out the connection between surface roughness and material removal rate. They modified the machining settings to achieve the optimal balance of surface roughness after machining process, as well as material removal rate. Rashis et al., 2020 studied the relationship between the machining parameters and performance of wear using DOE, Response Surface Methodology (RSM). They managed to develop the model adequately using RSM and done the validation experiments within the 90& prediction interval.

As a result, the goal of this article is to optimize the cutting-edge radius (CER) of the cutting tools as well as the width of cut during machining of DAC 55 steel in order to achieve superior machined surface quality using DOE, Full Factorial method. The important factor influencing surface roughness of machined surface materials has also been investigated, and the predicted or estimated value of surface roughness is calculated using Design Expert software.

2.0 EXPERIMENTAL PROCEDURE

The edge milling of DAC 55 was performed using MAZAK Vertical Center 410A-II Milling Machine. Cutting tools used for this study was supplied by HPMT. The cutting tools used were 6 mm uncoated tungsten carbide having four flutes with different CER which is 10, 20, and 30 micrometers.

For this study, the selected material is DAC 55 in solid block form. The DAC 55 consists of Chromium, Molybdenum, Vanadium, and Nickel with the composition of 5.2Cr-2.2Mo-V-Ni. The application of this steel is used for high performance die and squeeze die. The hardness for this material ranges from 50 to 53 HRC which has always been used for small die, squeeze die that are anti-heat crack (Hitachi Metals, 2015). In this experiment, Full Factorial was used as Design of Experiment (DOE). There are two (2) factors or parameters chosen; cutting-edge radius (CER) and width of cut with three (3) levels. Cutting speed, axial depth of cut and feed rate was set as constant. The parameters involved in this experiment are shown in Table 1. The number of experiments (9) is sufficient in analyzing the significant factor towards surface roughness and tool wear. On the other hand, the optimization was done by using Design Expert software.

Table 1: The parameters involved in the experiment.

Factors/level	**0**	**1**	**2**
Cutting-edge Radius (CER)	10 μm	20 μm	30 μm
Width of Cut (mm)	0.1	0.6	1.2
Spindle Speed (rpm)	2800		
Axial Depth of Cut (mm)	6		
Feed Rate (mm/min)	350		
Type of tool	Uncoated, 4 flutes, diameter 6 mm		

Figure 1: Mazak vertical center 410A-II milling machine.

Surface roughness after machining process (machined material) was measured using TIME 3220 Portable Surface Roughness Tester as shown in Figure 2. This surface tester has a measurement range of 400 µm. While for the tool wear of the cutting tool, it was measured using Dino-Lite Portable Microscope as shown in Figure 3. The microscope has a built-in scale that is integrated with the software that allows the wear of the tool to be measured using the software. The cutting tool is placed between the tool holder with the same flute facing up to ensure the same view can be observed.


Figure 2: TIME 3220 portable surface roughness tester.

Figure 3: Dino-lite portable microscope.

3.0 RESULTS AND DISCUSSION

Figure 4 shows the surface roughness of the machined surface material after 800mm distance travelled by using a new cutting tool. From the figure, lowest value of surface roughness of 0.183 µm was observed when milling with CER 30 µm and 0.1 mm width of cut. While the highest value of surface roughness is observed, 0.437 µm when machined using a cutting tool with CER of 10 µm and width of cut 1.2 mm. The milling test was performed until 4400 mm before the test was stop.

Figure 5 shows the same patent where the lowest surface roughness was observed on the DAC 55 machined surface with 30 µm CER is better (0.27 µm) compared with 20 µm (0.32 µm) and 10 µm CER (0.45 µm) when the width of cut is 0.1 mm. It is suspected that the lowest surface roughness value was obtained due to the stability of the cutting process. The chip flow is lesser on the machined surface and this result in the lower value of surface roughness. For the highest value of surface roughness, it is proposed that due to the microgrooves happening during machining. When the CER is 10 µm, the microgrooves occurred roughly on the machined surface. On the other hand, the lower surface roughness could be due to the smaller width of cut where lesser the energy required performing the machining operation. This will result in lower cutting forces, thus preserved the material properties against residual stress and the micro hardness changes at the subsurface (Hamdan et al., 2012). This is leading to the better surface quality of machined surfaces. This finding is similar with Fulemova & Janda, 2014, where they also discovered that the higher the cutting-edge radius, the better the quality of machined surface. It demonstrates that higher cutting-edge radius during machining is more stable and efficient. They also discovered that when the cutting-edge radius is increasing, the cutting tool experienced decreased tool wear.

There is no data that can be recorded when using a cutting tool with CER 10 µm when the width of cut is 1.2 mm. This is due to the cutting tool failing and breaking. The cutting tool failed because more material needed to be cut for the bigger width of cut and thus energy needs is higher. This phenomenon is suspected leads to the higher cutting forces and caused the tool fail and breakage (Edem & Balogun, 2018).

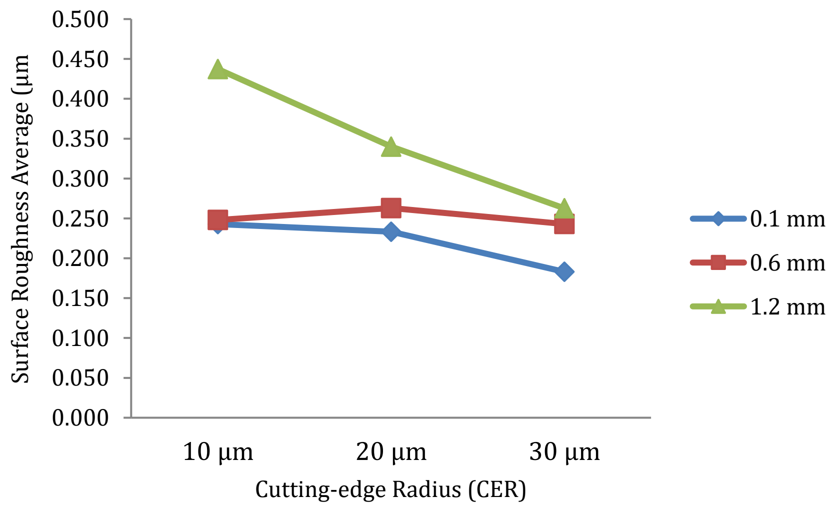

Figure 4: Surface roughness of new tool, after 880 mm distance travelled.

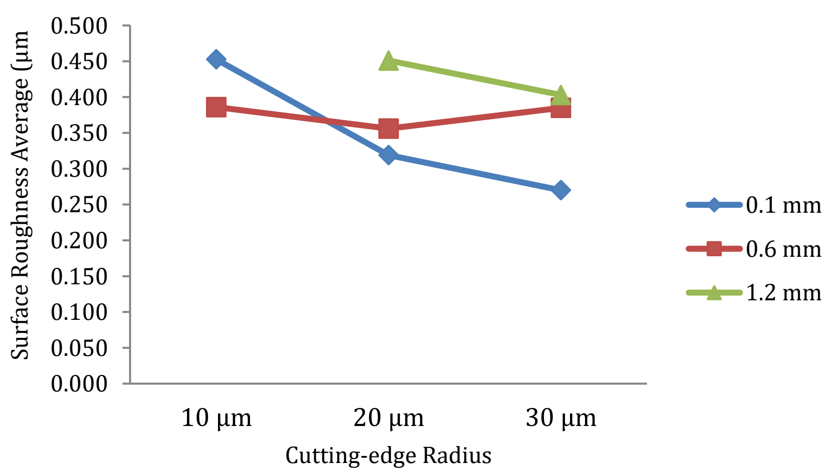

Figure 5: Surface roughness of tool, after 4400 mm distance travelled.

Figure 6 shows the tool wear when using the new tool and travelled 800 mm distance. From the graph, the significant factors contributing to the tool wear when using the new tool was not observed. The cutting tool with CER 30 µm and width of cut 0.1 mm is observed to be the lowest. The tool wear recorded was 0.033mm compared with cutting tool having smaller CER. . Also, from the Figure 7, it was observed that highest tool wear was recorded and observed when larger width of cut (0.6 mm and 1.2 mm) and lower CER (10 and 20µm) is applied. The highest tool wear was recorded (0.092 mm) when machining using a cutting tool with CER 20 µm and width of cut 1.2 mm. Thus, it suggested that machining with lower CER and larger width of cut resulting in higher tool wear. This finding is similar with Chuangwen et al., 2018, where they found that the milling width and depth of cut have significantly affect to the cutting force. When the width or depth of cut is increases, the cutting force also gradually increases due to the area of cutting is enlarged, which will increase the resistance of overall deformation, and this will increase the tool wear. There is no data that can be recorded when using a cutting tool with CER 10 µm when the width of cut is 1.2 mm. This is due to the failure and breakage of the cutting tool. Therefore, it is recommended that to perform milling of DAC55 with cutting tools having CER 30 µm and width of cut lesser than 1.2 mm.

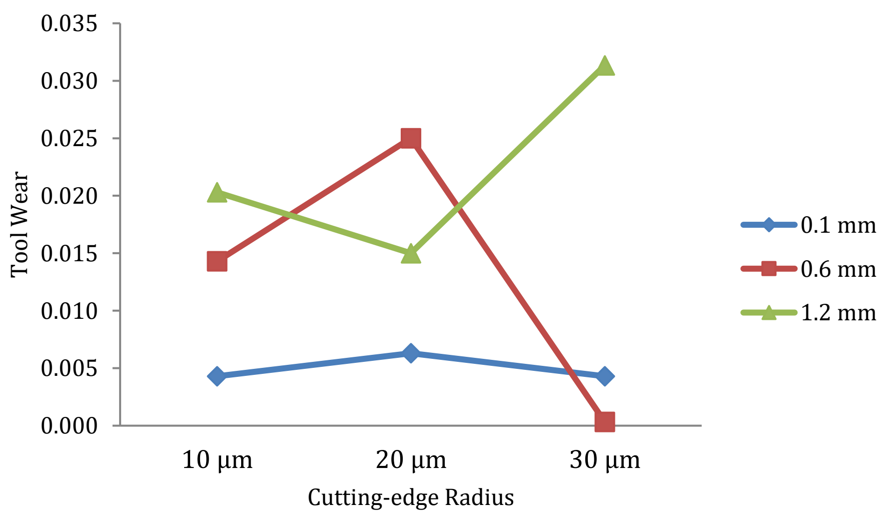

Figure 6: Tool wear of new cutting tool, after 880 mm distance travelled.

Figure 8 shows the tool wear of the cutting tool with 30 µm CER and 0.1 mm width of cut. From the figure, it was observed that the cutting tool experienced less wear which is 0.33 mm after 4400 mm distance travelled. The tool still can be used because the maximum tool wear for milling machining is 0.6mm. The lowest tool wear was recorded at 10 µm CER and width of cut 0.1 mm compared to the other at 20 µm CER and width of cut 1.2 mm which the cutting tool was worn-out. The highest tool wear of 0.092 mm was recorded after 4400 mm distance travelled. The SEM image in Figure 9 shows that the cutting tool experienced more wear compared to the other parameters.

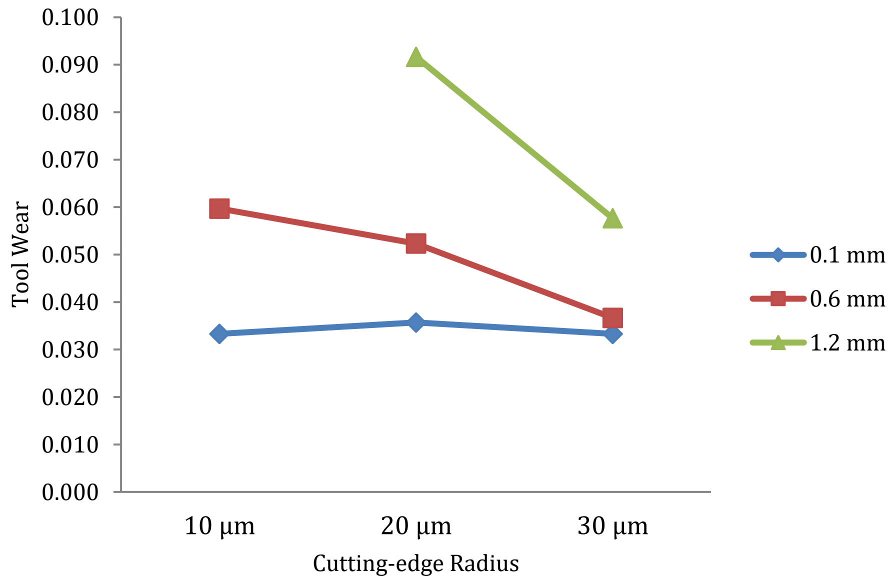

Figure 7: Tool wear of cutting tool, after 4400 mm distance travelled.

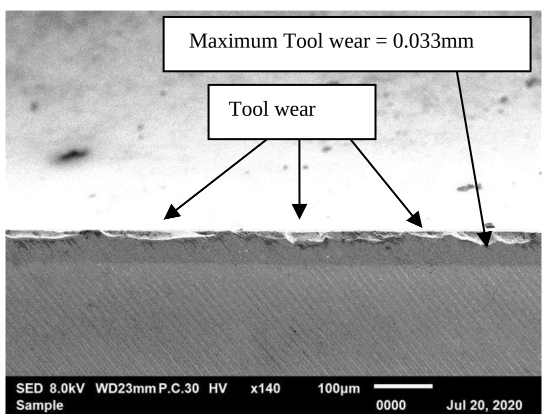

Figure 8: SEM image of end mill tool having 30 µm CER cutting tool and milling with 0.1 width of cut after 4400 mm distance travelled.

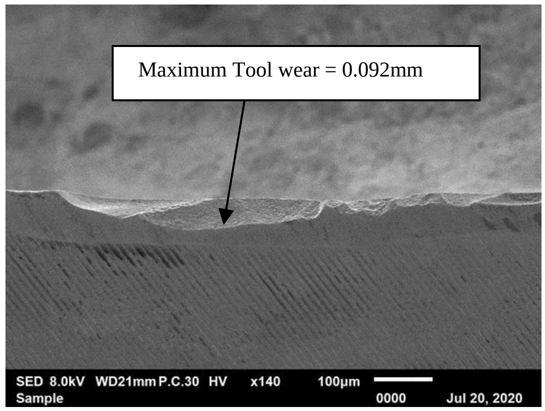

Figure 9: SEM image of end mill tool having 20 µm CER cutting tool and milling with 1.2 width of cut after 4400 mm distance travelled.

Table 2: ANOVA analysis for Surface Roughness significant factor

Source	**Sum of Squares**	**dff**	**Mean Square**	**F-value**	**P-value**	
Model	0.3748	8	0.0469	143.76	< 0.0001	Significant
A-Width of cut	0.1639	2	0.0820	251.46	< 0.0001	
B-Cutting-edge Radius	0.0904	2	0.0452	138.64	< 0.0001	
AB	0.0960	4	0.0240	73.65	0.0001	
Pure Error	0.0016	5	0.0003			
Cor Total	0.3765	13				

Table 2 shows the ANOVA analysis. From the figure, it was observed that the significant factor that contributed to the lower surface roughness is the width of cut. The F- value for width of cut shows higher than CER. This can be concluded from the table that width of cut plays the important roles in obtaining lower surface roughness compared to CER. From all graphs, the increasing of width of cut will resulted in increasing of the surface roughness and vice versa. For CER, it can be concluded that the increasing of CER, will resulted in a lower value of surface roughness. From the Table 2 also, it was observed that that both parameters give significant effect to the surface roughness, where the p-value for both parameters is less than 0.0001.

Table 3 shows the calculated value from the analysis of the experimental value that is analyzed by Design Expert software. The calculated value is for the surface roughness of the DAC Steel after the machining process according to each experiment setup. The calculated value for each cutting parameter is compared to the actual experimental value that is obtained from the machining of DAC 55. Then percentage error is then calculated based on the calculated value. From the percentage error calculated, the highest percentage is only 7.671% which makes this analysis using Design Expert very close to the actual experimental value. For the lowest percentage error, the value is zero which is coincidental the calculated value is similar to the experimental value.

Table 3: Calculated value and actual experimental value of surface roughness.

Cutting-Edge Radius (µm)	Width of Cut (mm)	Calculated Value (µm)	Actual Experimental Value (µm)	Percentage Error (%)
	0.1	0.455830	0.459000	0.695
10	0.6	0.358500	0.386000	7.671
	1.2	0.820500	0.827000	0.792
	0.1	0.321000	0.323000	0.623
20	0.6	0.356000	0.356000	0.000
	1.2	0.451000	0.451000	0.000
	0.1	0.270000	0.270000	0.000
30	0.6	0.386500	0.388000	0.388
	1.2	0.403000	0.403000	0.000

Solutions

9 Solutions found

Solutions for 9 combinations of categoric factor levels

Number	Width of Cut	Cutting Edge Radius	Surface Roughness	Desirability	
1	**0.1**	**30**	**0.270**	**1.000**	**Selected**
2	0.1	20	0.321	0.908	
3	0.6	20	0.356	0.846	
4	0.6	10	0.358	0.841	
5	0.6	30	0.387	0.791	
6	1.2	30	0.403	0.761	
7	1.2	20	0.451	0.675	
8	0.1	10	0.456	0.666	
9	1.2	10	0.821	0.012	

Figure 10: Final Solutions for optimization from the analysis of the experimental data.

Figure 10 shows the optimum parameters suggested by Design Expert in obtaining better surface finish of the machined surface and experienced less tool wear. From the Figure, it was indicated that to generate better results of surface roughness and tool wear, the combination of 30 µm of CER with 0.1 mm width of cut should be implemented. This can be concluded that the combination of 30 µm of CER and width of cut 0.1mm is believed to be the optimum parameters for machining of DAC 55.

CONCLUSION

In this paper, the experimental analysis was done for material DAC 55 using a 6 mm diameter of 4 flutes solid cutting tool with various cutting-edge radius (CER). The objective of the research was to find the optimum parameters to be selected in order to obtain better surface finish and at the same time experienced lesser tool wear. The influence of cutting parameters (CER and width of radius) was studied. Several conclusions could be made;

(a) The surface roughness was increased with the decreasing of CER. This can be explained by cutting tool having larger CER produced lower cutting forces and micro grooves as well as the chip flows produced was lesser and this resulted in the lower value of surface roughness. Therefore, the value of CER is suggested to be 30 µm.
(b) The surface roughness is increasing with the increasing of width of cut. The more material needed to be cut, will result in the increasing of energy and forces, thus the machined surface becomes rougher. The suggested value of width of cut is 0.1mm.
(c) From the Design Expert software, the width of cut is proposed to be more significant to the surface roughness compared with CER. It can be concluded that the surface roughness value could be reduced as the value of the width of cut reduced.
(d) The optimum parameters in obtaining the lower surface roughness and tool wear are suggested to be 30 µm for CER and 0.1mm for width of cut.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Production Lab, Department of Manufacturing and Materials Engineering, Kulliyyah of Engineering, IIUM and HPMT Industries Sdn Bhd.

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