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Testing the Cutting Depth Capability of A 16 Mm Hss-Co Endmill on S50c Material Using the Lagun Fu 100 Milling Machine

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The milling process is a conventional process that requires a cutting tool harder than the workpiece material. In the milling process, one of the cutting tools or cutters used is the HSS endmill type which has a hardness value of around 735 HB (Hardness Brinell). The material used in this study is an S50C which has a 172 HB. The machine used in this study is a Lagun FU 100 milling machine. The testing process uses a cutting speed of 18 m/min, a spindle speed of 350 rpm, and a feed rate of 30 mm/min. The largest tangential force that occurs is obtained when performing a cutting depth of 40 mm with a value of 2220 N, the torque on the cutter is 17.76 Nm, and the power on the motor is 0.897 kw. The calculation of the deflection on the chisel obtained the largest value of 0.093 mm based on simulation, while the largest stress value based on the simulation results is 224,5 N / mm ^ 2. The test results on the Lagun milling machine showed that the HSS-Co end mill was able to cut S50C material to a depth of 40 mm.
Keywords: Depth of cut, S50C, Endmill HSS-Co, Tangential forceenvironment for SME sustainability.

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1. Introduction

Milling is a machining operation to cut the workpiece using a rotating cutting tool so that it becomes the desired shape (Groover, 2012). The milling process is a conventional process that requires a cutting tool that is harder than the workpiece material.

The use of cutting tool material in milling machining greatly affects the machining results. One of the cutting tool materials in the milling machining process is HSS (High-Speed Steel). Although there are currently many types of cutting tool materials used in the milling machining process, HSS materials are still used to cut materials in the milling process, especially for soft materials.

One type of cutting tool used in the milling process is the endmill. Endmills are used to create various cavity and groove profiles in basic milling machining (Paul et al., 2020). One of the endmill materials is HSS. HSS endmill is commonly used as the main cutting tool in learning media for basic milling machining process (Firdaus & Susanti, 2021). The relatively lower cost compared to carbide endmill material as well as the not-so-fast cutting speed are the reasons why HSS endmill is used as a student learning tool. Before the widespread use of carbide endmills, HSS endmills were the main choice in the milling machining process. HSS has a hardness value between 658-752 HB (Brinell Harness). From these data, HSS is a tough material with a relatively cheaper price and HSS endmills can be sharpened again, which is one of the factors that HSS endmills are used for milling machining processes.

In milling machining, the workpiece is an object to form a certain desired shape according to the capabilities of the machine and its working drawings. One of the workpiece materials capable of milling processing is S50C material. S50C is a type of machining steel that is included in medium carbon alloy steel (medium carbon steel) around 0.50%C with a hardness value between 160-220 HB (Beyond Steel & Metal, n.d.). S50C steel is often used as the main material for machine tools and construction on machines such as dowels, pegs, gears, and shafts (Rizal Ainur Rachman & Mahendra Sakti, 2020). The superior properties of S50C material are slightly ductile, capable of machining, and tough (Rizal Ainur Rachman & Mahendra Sakti, 2020). From these data, it can be concluded that HSS is able to cut S50C material because it has a higher HB value than HSS material.

In addition to the cutting tool's ability to cut workpieces, machine capabilities also need to be considered. The conventional milling machine used must have specifications that are capable of carrying out the cutting process. One of the conventional milling machines owned in the Manufacturing laboratory is the Lagun FU 100 machine. The specification of this machine's spindle motor is 1.5 Kw and its automatic feeding motor power is 0.55 Kw.

The use of a Lagun milling machine that has a spindle motor power of 1.5 kilowatts is to determine the ability of the effective depth of cut that can be done on S50C material using an HSS-Co end mill. This research is expected to be a reference for performing cutting operations with similar material specifications and cutting tools. The ability to cut the workpiece in one pass is also influenced by the HSS endmill cutting tool used. In this case, a 16mm diameter HSS endmill was used in the study to determine its ability to cut S50C workpieces in one pass based on the depth of cut. Currently there are many media to conduct a test, one of which is using 3D software to simulate what will happen in a test. One of the 3D software that is able to simulate how the ability of a cutting tool when cutting is ANSYS software. The result of this simulation is to see which part gets the biggest stress indicated by a change in color. This simulation process is used to compare the simulation results in the form of deflection and cutting tool stress in the software with those that occur when testing with the Lagun FU100 milling machine.

Cutting using HSS endmills in the milling process is often done with a relatively small depth of cut, which can make the cutting process take longer.Cutting is also done without knowing the power capability of the engine motor, so the process to cut to an effective depth cannot be done. Therefore, research is needed to obtain data and become a reference about the cutting process based on depth of cut using HSS Endmill on S50C material in Lagun FU 100 milling machine which has a spindle motor power of 1.5 kilowatts.

This study was conducted to determine the ability of the depth of cut capable of HSS Endmill cutting tools cutting S50C material on the Lagun FU100 milling machine compared to the results of the simulation of ANSYS software student version.

2. Research Method

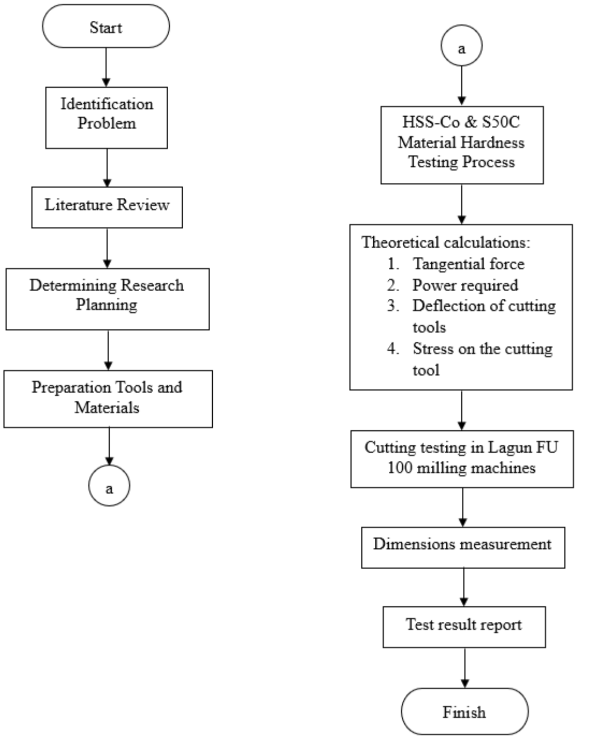


Figure 1. Research Flow Chart

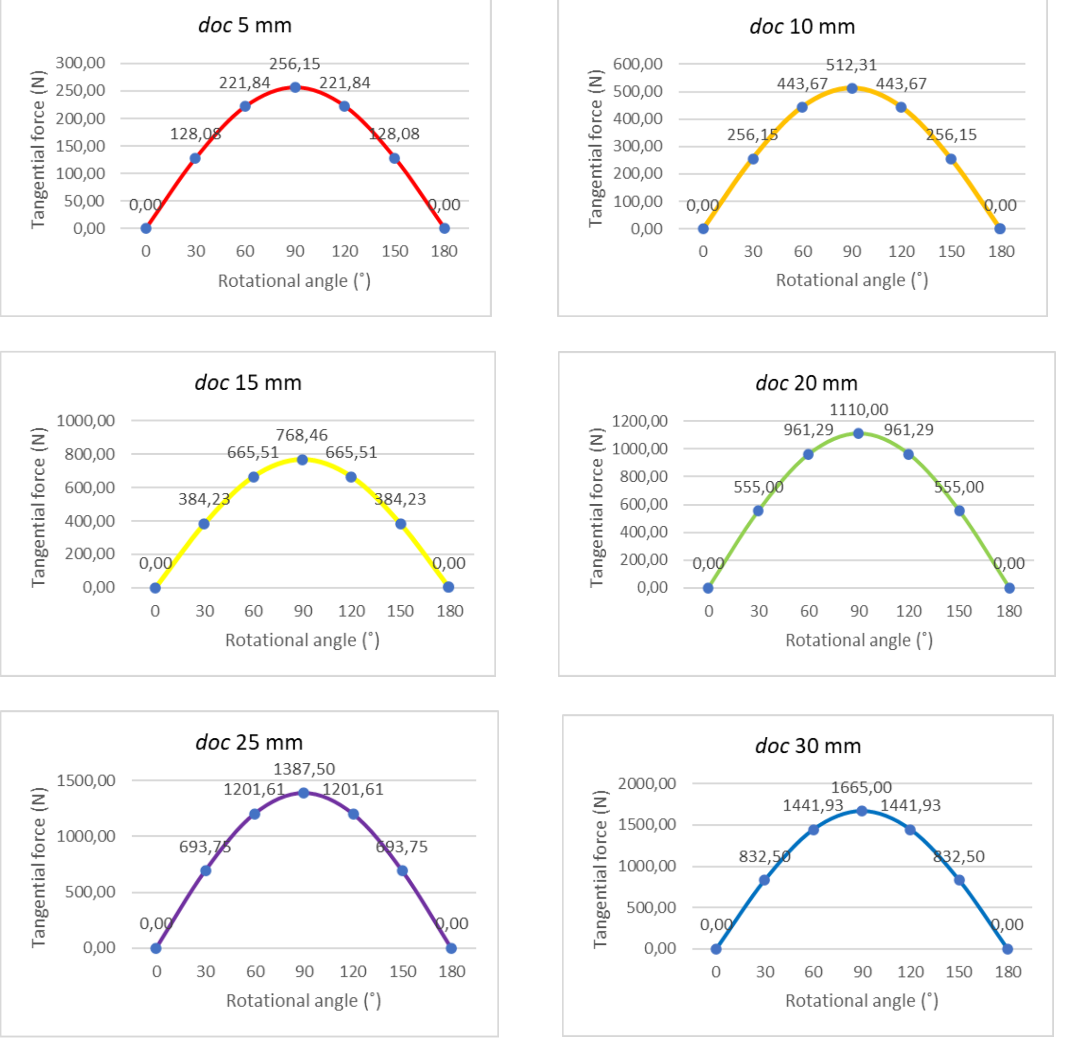
In this study, an experimental research method was used. The experimental research method is a research method used to find certain influences on controlled conditions or variables (Farhan Arib et al., 2024). Authors used a method of processing data with data visualization. The data visualization method is data processing that is displayed in graphical form for easy understanding (Al Ghivary et al., 2023).

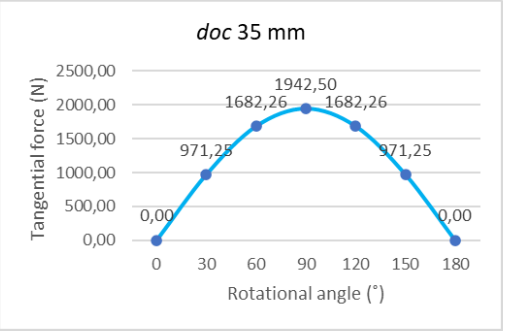
3. Result and Discussion

Data obtained that the feed/tooth for milling for alloy steel materials including S45C/S50C is taken values between 0.019-0.030 mm/tooth (Afolalu et al., 2018; Çiçek et al., 2021)so, after calculating to determine the feedrate, obtained numbers 26-42 mm/min. The availability of feed rate values on the Lagun FU100 milling machine with calculations that approach is to use a 30 mm/min feedrate. The spindle rotation speed used is 350 rpm.

The test process was carried out by increasing the depth of cut at intervals of 5 mm to 40 mm in each cutting process with one direct cut without coolant. Calculation of deflection and stress values on the end mill that has the largest tangential force value will be calculated using ANSYS simulation and the dimensions of the finished cut will be measured using a vernier caliper.

Theoretical calculations to calculate the amount of tangential force that occurs at each cutting depth are carried out to determine the value of the largest tangential force obtained to become a reference number in calculating the amount of torque that occurs in the end mill cutter and then calculating the power required to cut to a depth of 40mm. the required power will be compared with the motor power owned by the milling machine. the results of the comparison will determine whether it is up to a depth of 40 mm.





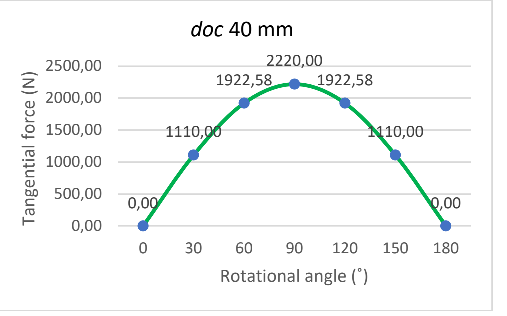


Figure 4. Tangential force in cutting area (a) doc 5 mm, (b) doc 10 mm, (c) doc 15 mm, (d) doc 20 mm, (e) doc 25 mm, (f) doc 30 mm, (g) doc 35 mm, (h) doc 40 mm.

Based on figure 4 we can conclude that when the cutting edge is at a 90-degree angle, the tangential force experiences its highest value This maximum tangential force value is used to calculate torque and power.

The tabulated data is then transformed into a graph, which shows the tangential force values against cutting depth. From the graph, it is evident that the tangential force at a 90-degree angle increases linearly with cutting depth. Therefore, it can be concluded that greater cutting depth results in a larger tangential force at a 90-degree angle.

Calculating the torque value on the cutter. The torque value on the cutter is the multiplication value of the tangential force and the radius of the cutter. The tangential force used to calculate the amount of torque that occurs on the cutter uses the largest tangential force at each cutting depth, in this case using the tangential force when the cutting edge is at a 90º angle.

Table 5 - Torque on the cutter which is influenced by the tangential force value.

Doc [mm]	Tangential Force [N]	Torque at cutter [Nm]
5	256,15	2,05
10	512,31	4,10
15	768,46	6,15
20	1110	8,88
25	1387,5	11,10

30	1665	13,32
35	1942,5	15,54
40	2220	17,76

The tangential force values that appear in table 5 are obtained from the highest values in figure 4 when cutting at a 90º angle at each cutting depth.

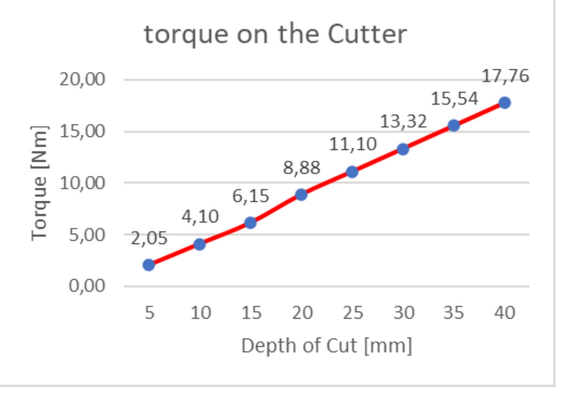


Figure 5. Torque on the cutter.

The graph shows the torque on the cutter against the cutting depth. From the graph it is known that the torque value experiences a linear increase against the cutting depth. Thus, it is found that the greater the cutting depth performed, the greater the torque on the cutter.

Table 6 - required power for cutting S50C used end mill HSS-Co in Lagun milling machine.

doc (mm)	Tangential force (N)	power at cutter [Nm/s]	power at motor [Kw]
5	256,15	0,08	0,10
10	512,31	0,15	0,20
15	768,46	0,23	0,31
20	1110,00	0,33	0,44
25	1387,50	0,42	0,56
30	1665,00	0,50	0,67
35	1942,50	0,58	0,78
40	2220,00	0,67	0,89

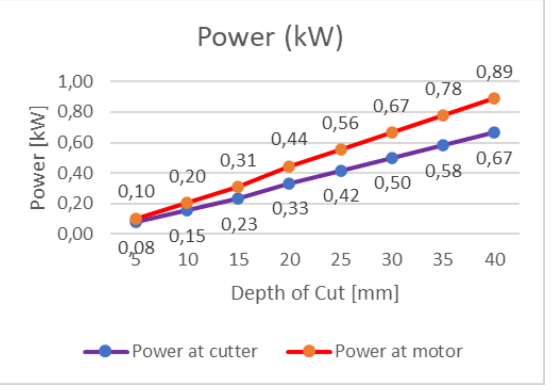


Figure 6. Power to cutting depth graph.

The tabulated data is converted into a graph. The graph shows the value between the power on the cutter and the power on the motor against the cutting depth. From the graph it is known that the power required increases with the cutting depth. Thus, it is found that the greater the cutting depth, the greater the power required. The power value required from the theoretical calculation results compared to the motor specifications on the Lagun FU100 milling machine, is known as stated in table 1 regarding the Lagun FU100 milling machine, the spindle motor power is 1.5 Kw, while the calculation results of the power required on the largest motor are 0.897 Kw.

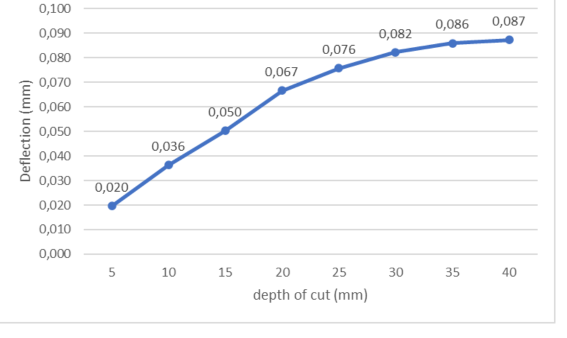


Figure 7. Graphic deflection to depth of cut.

Figure 7 shows data regarding the amount of deflection in the cutter end mill relative to the depth of cutting. The graph shows that the greater the depth of cutting carried out, the greater the deflection value of the end mill cutter. The allowed deflection value is L/360 (Koo, 1967). If length L = 55 mm then the permissible deflection is up to 0.153 mm. Thus, the deflection figure that occurs at the greatest cutting depth is still included in the allowable deflection value.

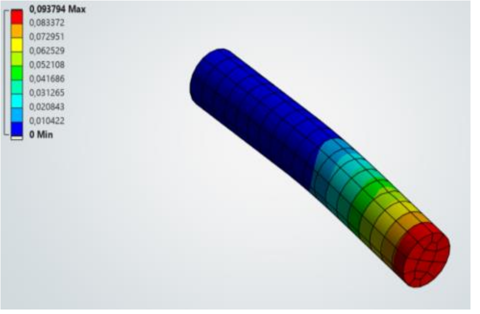


Figure 8. Deflection results from the ANSYS simulation for a cutting depth of 40 mm.

The difference between the values and the simulation is based on several aspects, including that the simulation has more complex calculations and the shape of the cutting tool is more detailed compared to calculations using the deflection formula for the cantilever rod. This simulation result value is also still below the permitted deflection value, namely 0.153 mm.

Deflection values based on experimental results were carried out by taking measurements using a caliper to measure the amount of deflection from position a1 (start of cutting) to position a2 (end of cutting) as shown in figure 9.

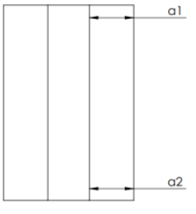


Figure 9. Measurement od deflection on the workpiece.

Table 7 - Deflection measurement result.

no	doc [mm]							
	5	10	15	20	25	30	35	40
a1	6,28	7,92	4,32	9,7	6,92	5	5,54	5,7
a2	6,22	7,88	4,2	9,52	6,7	4,88	5,42	5,5
deviation	0,06	0,04	0,12	0,18	0,22	0,12	0,12	0,2

From these data, the largest deviation occurred when cutting 25 mm at 0.22 mm.

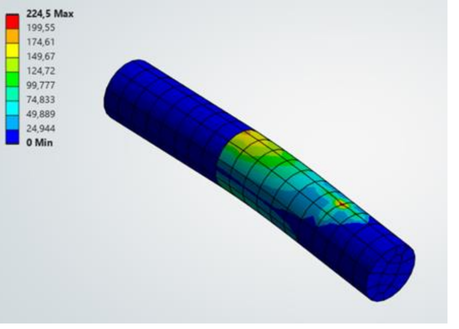


Figure 10. Static structural ANSYS simulation.

The cutting depth process of 40 mm which is the cutting process becomes the largest stress value in the test. It can be seen that when performing the 40 mm cutting process, the end mill experiences the largest stress of 224.5 N / mm ^ 2, this stress value is below the yield strength limit of HSS-Co which has a yield strength value of up to 3250 N / mm ^ 2.

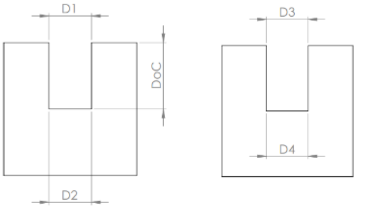


Figure 11. Workpiece measurement after cutting process.

Table 8 - Measurement result.

No	Measurement result (mm)				
	doc	D1	D2	D3	D4
1	5	15.96	15.96	16	16
2	10,4	15.98	15.98	16.02	16.06
3	15,2	15.96	16	15.96	15.98
4	20,2	15.92	16	15.98	16
5	25,1	16.1	16	15.96	16
6	30,4	16	15.98	16.1	16
7	35,1	15.98	15.98	16	15.94
8	40,2	16	15.98	15.74	15.78

The measurement results are then averaged per cutting depth. The average measurement table is shown below:

Table 9 - average measurement of D1, D2, D3, and D4.

No	Average
1	15,98
2	16,01
3	15,98
4	15,98
5	16,02
6	16,02
7	15,98
8	15,88

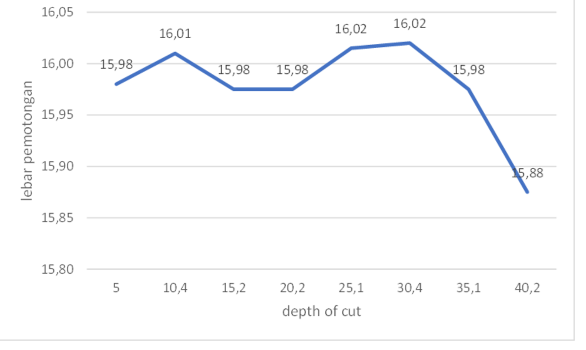


Figure 12. Graphic of average measurement of D1, D2, D3, and D4.

Results and Discussion is a section that contains all scientific findings obtained as research data. This section is expected to provide a scientific explanation that can logically explain the reason for obtaining those results that are clearly described, complete, detailed, integrated, systematic, and continuous.

It can be concluded that the HSS end mill with a diameter of 16 mm is capable of cutting up to a cutting depth of 40 mm on a Lagun milling machine. However, the surface results, especially on the workpiece walls, begin to wavy when the cutting depth is 25 mm to 40 mm. Then the Y-axis feed starts to become unstable and this causes the machining time to increase.

4. Conclusion

This research was conducted to determine the cutting depth capability of a HSS end mill with a diameter of 16 mm on S50C material on the Lagun FU100 milling machine. The results of this test produced several conclusions, including that conceptually, based on the specifications of the Lagun FU 100 milling machine, the 16 mm diameter HSS end mill is capable of cutting S50C material to a depth of 40 mm, which is the cutter's flute length limit. which is used. Based on the stress value calculation carried out by the student version of ANSYS software using the static structural feature, the stress value obtained when carrying out a cutting depth of 40 mm is 224.5 N/mm^2 and this figure is still below the yield strength figure for HSS-Co of 3250 Nm ^2. Based on the results of tests carried out on the milling machine, it is known that the 16 mm diameter HSS end mill cutter is capable of cutting S50C material to a depth of 40 mm. The cutting results for cutting depths from 25 mm to 40 mm have contour lines on the workpiece wall. The machining time from a cutting depth of 25 mm to a depth of 40 mm continues to experience a longer cutting duration, because the automatic feed is unable to run constantly at a speed of 30 mm/minute. Therefore, the recommended cutting is up to a depth of 20 mm.

The suggestion for further research is to carry out the cutting force calculation process using a dynamometer to obtain an accurate cutting force value. then, carry out the cutting simulation process using ANSYS software using the Explicit Dynamic feature or similar software that can carry out dynamic simulation processes and measure the surface results using the Surface Roughness Tester tool to obtain the surface roughness value of the machining results.

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