Surface Integrity Study of AISI 1045 Material in Dry Machining Using Coated Carbide Tool

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ABSTRACT

In metal cutting processes, the source of surface integrity deviation is a combination of several factors. The surface roughness parameter (Ra) is sufficient to determine the quality level of the surface packaging of a product, so it is widely used as a parameter to determine the surface packaging level of a product. Carbide tools dominate modern applications in the metalworking industry and are the preferred choice for metal cutting processes. Carbide tools can be improved through a coating process. In particular, the purpose of this study was to obtain surface roughness and optimum cutting conditions for dry machining of AISI 1045 materials using coated carbide tool when used in dry machining as well as for the development of research and development with research design analysis of the results of student practicum processes in laboratories, especially surface packaging material analysis. The material used is AISI 1045 with PVD TiAlN-TiN coated carbide tool. Combination machining process of cutting conditions, namely cutting speed, feed and depth of cut. Surface roughness test results on AISI 1045 test material with uncoated carbide tool surface roughness value = 9,042µm in cutting conditions: v= 235 m/min; f= 0.05mm/put; a=0.5mm; tc= 5.23 min. And the results of the surface roughness test on the AISI 1045 test material with PVD coated carbide tool with the best average surface roughness value = 6,135µm in cutting conditions: v=235 m/min; f=0.75 mm/put; a=1mm; tc=5.30 min.

I. Introduction

One industry that has the opportunity to dominate the market and its development is increasing rapidly is the component or machine tool manufacturing industry [1]. In this industrial connection, it is always related to metalworking, namely metal cutting processes or machining processes using cutting tools. In the metal manufacturing industry, one of the main issues of concern is environmental issues, due to the product, process or production system. The interest in human health and ecology has made the metal cutting industry develop cutting methods that are friendly to the environment and health and have the aim of improving efficiency, reducing production costs, increasing productivity and minimizing cycle time and at the same time providing comfort to the environment and occupational health [2].

An alternative option to wet machining is dry machining, because in addition to no large amounts of used cutting fluid to contaminate the environment there is no mist of cutting fluid particles to harm the operator and cutting chips to be contaminated with cutting fluid residue.

Carbide tool dominate modern applications in the metal working industry and are the best choice for metal cutting processes. Carbide tool have been proven to produce the best cutting results, especially in the lathe cutting process. In addition to showing good performance value, carbide tools are also tools that have good economic value [3].

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Along with the rapid development of technology, for the purpose of increasing the performance and wear resistance of cutting tools used for machining processes, carbide tools can be further improved through a coating process. Recently, tools coating technology with various coating materials and coating methods has been developed [4]. The main function of the coating material is as a solid lubricant which functions to reduce friction and heat generation during the cutting process [4].

To obtain more comprehensive information about the performance of carbide tool coating materials which are widely used in the metal cutting industry, especially for producing aluminum-based products, it is necessary to conduct a study related to the performance of carbide tool coatings, this is in line with the results of research [4], which reported that the performance of coating materials on coated carbide tools does not function as expected when used in milling operations of non ferrous metal materials. In his report, he concluded that there was a new type of wear and it was called coating delamination. Then in the study of mechanical and chemical load characterization for dry turning operations of Al 6061 material using diamond film coated carbide tools, wear and abrasion of the coating (abrasive) occurred. The presence of the tools diamond film layer element is no longer perfect [5-6].

Based on the explanation above and the facts that have been put forward by several previous researchers, that in the metal cutting process, the source of the deviation of the surface packing characteristics is one of the factors, therefore it is necessary to conduct a study that can explain the characteristics of the surface packing on AISI 1045 materials by dry turning method using coated carbide tools.

This research is also a research and development with a research design that analyzes the results of student practicum processes in laboratories, especially laboratories related to material analysis. For this reason, the response to the research design module that was developed was included in the very positive category. Thus, it is hoped that the implementation of practicum modules based on material analysis research designs can significantly improve science process skills and student learning outcomes. It is for this reason that this research is important to do.

And specifically the purpose of this study is to obtain the surface roughness value (Ra) and the optimum cutting conditions for dry machining of AISI 1045 materials using plated carbide tool as well as for development with research design analysis of the results of student practicum processes in laboratories, especially laboratories related to material analysis including defects or flaws, lay, waviness and roughness.

The results of this study are expected to provide benefits for the academic world and the metal cutting industry in general and for researchers in particular, as for these benefits, namely contributing to the provision of data and information in planning the dry machining process of ferro metal materials, especially information on the surface packaging of AISI 1045 turning materials. dry using plated carbide tool as well as for the development of practicum modules with research designs analyzing the results of student practicum processes in related laboratories.

II. Research methods

A. *Dry Machining*

In the concept of dry machining, cutting fluid is no longer used in large quantities even if it may be completely eliminated [7]. Efforts to reduce the use of cutting fluids in metal cutting processes continue to be made based on ecology, health and economy. Technical challenges in dry machining of metal cutting processes arise due to the nature of the environment [7].

Generally used cutting fluid is stored in containers and then buried on the ground, this will obviously damage the environment and the applicable environmental laws prevent this. The metalworking fluid safety and health administration agency standard advisory committee has recommended the limit of hazardous elements in cutting fluids for machining processes, namely 0.5÷5.0 mg/m3 [8-9].

Through the dry machining method, it is hoped that besides being safe for the environment and also safe for health, dry machining can also reduce production costs around 16-20% [8-9]. However, the dry machining method also has several problems in its application, among the problems that will be encountered include the friction that occurs between the surface of the workpiece and the cutting tool, the speed of chip exit, the high cutting temperature and the problems mentioned above are all related to machining parameters.

B. *Characteristics and Terminology of Lathe Process*

In this lathe process the workpiece gripped in the chuck rotates about its axis, while the tool as a cutting chisel moves translationally to slice the workpiece along the workpiece axis or against its diameter. Although the definition is simple, the metal cutting process is very complex. Figure 1. is a schematic of the lathe process, where Main Shaft Rotation (n), Infeed (f) and Depth of Cut (a).

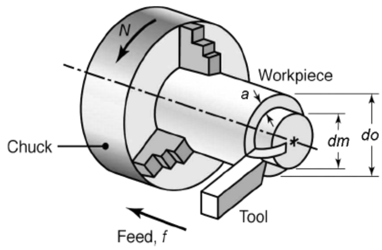

Fig. 1. Schematic illustration of the lathe process

According to [11], there are five basic elements in the machining process, namely:

1. Cutting speed : v (m/min)
2. Feeding speed : vf (mm/min)
3. Depth of cut : a (mm)
4. Cutting time : t_c (min)
5. Material removal rate : Z (cm3/min)

In order to be able to determine the cutting conditions, according to [10], a formula can be used for the main parameters in the lathe machining process, namely:

Cutting speed : $v = \frac{\pi.d.n}{1000}$ (m/min) (1)

where d = average diameter (mm)
n = rotation of the machine (rpm)

Feeding : f = mm/put

Feeding speed : vf = f.n (mm/min) (2)

Depth of cut : $a = \frac{do-dm}{2}$ (mm) (3)

where do = initial diameter (mm)
dm = final diameter (mm)

Cutting time : $t_c = \frac{lt}{Vf}$ (min) (4)

lt = machining length (mm)

Material removal rate : Z = A.v (cm^3/min) (5)

C. *Surface Packing Characteristics*

Various methods have been carried out to explain the characteristics of the surface packaging produced by a machining process, where the machining process can cause irregularities in the characteristics of the product surface packaging.

The irregularity of the surface packing characteristics is divided into 4 types namely*:*

1. Defect or Flaws: Is a product surface defect that occurs in the machining process for example holes, cracks, tears on the surface of the product.
2. Lay: Is the trace of the cutting direction of the chisel eye on the surface of the product due to the machining process.

3. Waviness: Is a periodic irregularity on the surface of the product with a wavelength that is clearly greater than the depth. This waviness can be caused by vibrations that occur during the machining process, and also due to the deflection of the chisel. Carbide tools dominate the cutting used.
4. Roughness: Roughness is almost the same as waviness but roughness is within a smaller range.

For more details regarding the irregularity of the characteristics of this surface packaging can be seen in Figure 2.

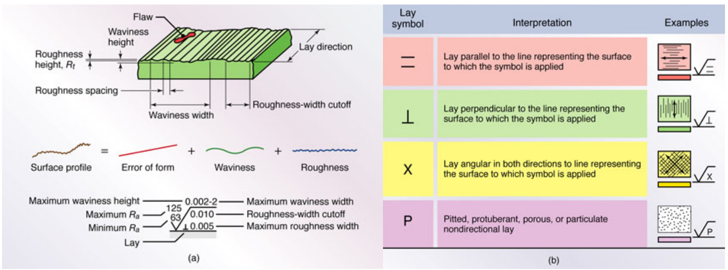

Fig. 2. (a) Standard terminology and symbols used to describe the surface finish (μ). (b) Common surface symbols

The parameter used to determine the level of surface roughness commonly used is the arithmetic mean value (Ra), taking into account Figure 3, Ra can be obtained using the formula:

$$Ra = \frac{a+b+c+d+\cdots}{n} \tag{6}$$

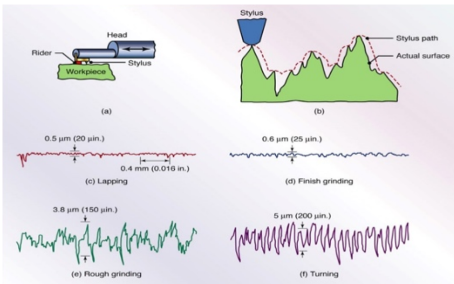

Fig. 3. Surface texture of a product

III. Method

A. *Materials*

AISI 1045 is in the form of a billet (round bar), with an effective length of 210 mm and a diameter of 88 mm. This material is commonly applied to machine chisels, gears, construction, machinery industry, bridge construction, springs, etc [11]. The material for the test object is shown in Figure 3. The chemical composition, mechanical properties and hardness of this material are presented in Table 1, Table 2 and Table 3.

Fig. 3. AISI 1045 test object material

Table 1. Chemical composition of AISI 1045

Fe (%)	C (%)	Si (%)	Mn (%)	p (%)	s (%)	Cr (%)	Mo (%)	Ni (%)	Ni (%)	Al (%)
97.8	0.796	0.258	0.790	0.025	0.011	0.151	0.089	0.008	0.039	0.055
Co (%)	**Cu (%)**	**Nb (%)**	**Ti (%)**	**v (%)**	**w (%)**					
0.001	0.009	0.005	0.005	0.005	0.015					

Table 2. Mechanical properties of AISI 1045

No.	Characteristic	Mark
1	Kekerasan (Brinell 3000 kg)	86 – 388
2	Kekuatan Tarik Maksimum (MPa)	276 – 1883
3	Kekuatan Luluh (MPa)	186 – 758
4	Modulus Elastis (GPa)	190 – 210
5	Poisson Rasio	0,27 – 0,3
6	Konduktivitas Termal (W/m-K)	24,3 – 65,2
7	Massa Jenis (1000 kg/m^3)	7,85
8	Titik Cair (°C)	1410

Table 3. AISI 1045 steel hardness

Materials	Test-I	Test-II	Test-III	HRB/HV
Baja AISI 1045	93.5	93.0	93.5	93.3/200

The cutting tools used in this study were manufactured by Sandvick Coromant, namely carbide coated tools made of Titanium Aluminum Nitride (TiAlN) and Titanium Nitride (TiN) produced through the PVD process. The carbide cutting tool is ISO standard DCGX 11 T3 04-AL, with the identity GC 1105. Figure 4 shows the dimensions of the GC 1005 coated carbide tool, the specifications of the tool can be seen in Table 4 below [12].

Type	Dimensi (mm)			
DCGX 11 T3 04-AL	re	l	iC	S
	0,4	11	9,525	4

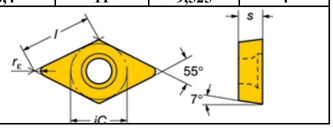

Fig. 4. GC1005 plated carbide chisel dimensions

B. *Tools*

1. Rockwell Hardness Tester

To determine the hardness value of the test material, the test object is examined using the Rockwell Hardness Tester, the tools used can be seen in Figure 5.

Fig. 5. Rockwell hardness test Matsuzawa

2. Thurning Machine

Machining is done using a WH-530X200G lathe, the tools used can be seen in Figure 6.

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Fig. 6. Thurning machine WH-530X200G

3. Surface Roughness Tester

To determine the surface roughness (Ra) value of the AISI 1045 test material after the machining process, the surface roughness measurement of the material was carried out using the Surface Roughness Tester SE300, ME-52083 Series. Surface Roughness Tester seen in Figure 7.

Fig. 7. Surface roughness tester

Design of Research Activities and Set-up:

1. Setting up data collection equipment including:
   - WH-530X200G lathe and prepared coated carbide cutting tools
   - Tool holder
   - AISI 1045 test object material
   - Surface Roughness Tester
2. Check the condition of the lathe which must be really stiff and not speeling
3. Adjust the diameter of the test object at the engine speed (rpm) on the WH-530X200G lathe
4. Starting the machining step by determining the engine speed (rpm), feed (f) and depth of cut (a)
5. Execute the machining process according to predetermined cutting conditions.
6. Retrieve data on the surface roughness value (Ra) of the AISI 1045 test material:
   - Tool holder After machining is done with the machining length (lt) of the workpiece, the tool is placed on a symmetrical stand
   - Surface Roughness Tester Place the detection indenter on the test material
   - Record of the measurement results on the monitor of the Surface Roughness Tester tool
   - Perform measurements at an angle of 120º for each test material.

C. *Tools*

Collection was carried out at cutting conditions according to the recommendation data and is presented in Table 4.

Table 4. Cutting condition plan

No.	v (m/min)	f (mm/put)	vf (min)	a (mm)	d (mm)	d_1 (mm)	n (rpm)	lt (mm)	tc (min)	Ra (mm)
1	235	0.05	44	0.5	86	85	880	230	5.23	-
2	235	0.075	66	1	87	85	880	350	5.30	-
3	235	0.1	88	1.5	88	85	880	480	5.45	-

IV. Results and Discussion

From the results of the surface roughness test (Ra) on the AISI 1045 test material with PVD (TiAlN/TiN) coated carbide tools as presented in Table 5 and Figure 8.

Table 5. Cutting condition

No.	v (m/min)	f (mm/put)	vf (min)	a (mm)	d (mm)	d_1 (mm)	n (rpm)	lt (mm)	tc (min)	Ra (mm)
1	235	0.05	44	0.5	86	85	880	230	5.23	0.05
2	235	0.075	66	1	87	85	880	350	5.30	0.075
3	235	0.1	88	1.5	88	85	880	480	5.45	0.1

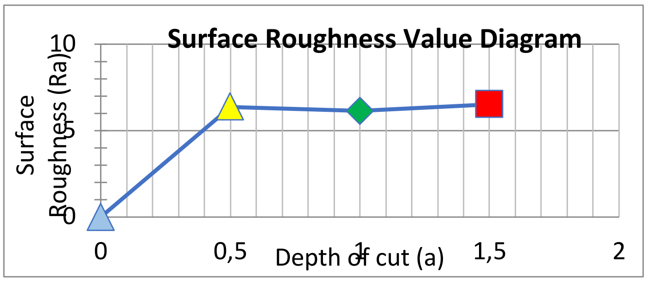

Figure 8. Surface roughness (Ra) Vs depth of cut diagram (a) Cutting conditions 1, 2 and 3, PVD coated carbide (TiAlN/TiN) tools

Investigation of the surface roughness values of the machining results of the AISI 1045 test material in the cutting conditions with a depth of cut, namely: a = 0.5 mm and a cutting time, namely: tc= 5.23 min, carried out under the machining conditions listed in Table 4. On the results of the surface roughness analysis of each axis (line) shaft in the analysis point area, as presented in Table 5 and Figure 9.

Table 5. Surface roughness value AISI 1045 cutting conditions 2

Coated Carbide Tool (TiAlN/TiN) PVD			AISI 1045
No.	**Line**	**Ra**	**Nilai**
1	120°	Ra_1	6.395
2	240°	Ra_2	6.394
3	360°	Ra_3	6.352
		$\vec{Ra}$	**6.380**

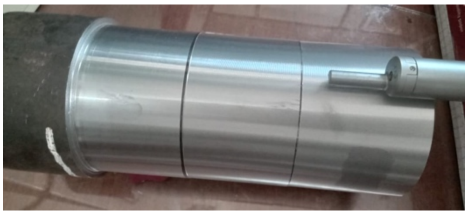

Fig. 9. Surface roughness value at cutting condition 1 (v= 235 m/min|f= 0.05 mm/put|a=0.5 mm|t_c= 5.23 min)

As shown in Figure 9 at cutting conditions 1, the surface roughness value on each line is the degree of cutting. On the 120° line the surface roughness value is 6.395µm, on the 240° line the surface roughness value is 6.395µm and on the 360° line the surface roughness value is 6.352µm. For the three measurement lines, an average surface roughness value of 6.380µm is obtained at the condition of the depth of cut a = 0.5 mm and the cutting time tc = 5.23 min.

In investigating the surface roughness value of the machining results of the AISI 1045 test material at the cutting conditions with a depth of cut, namely: a = 1 mm and a cutting time, namely: tc = 5.30 min, carried out under the machining conditions listed in Table 4. The results of the surface roughness analysis of each axis axis in the analysis point area, as presented in Table 6 and Figure 10.

Table 6. Surface roughness value AISI 1045 cutting conditions 2

Coated Carbide Tool (TiAlN/TiN) PVD			**AISI 1045**
No.	**Line**	**Ra**	**Nilai**
1	120°	Ra_1	6.165
2	240º	Ra_2	6.105
3	360°	Ra_3	6.134
		$R\vec{a}$	**6.135**

Fig. 10. Surface roughness value at cutting condition 2 (v= 235 m/min|f= 0.75 mm/put|a=1 mm|t_c= 5.30 min)

As shown in Figure 10 in the cutting condition 2, the surface roughness value on each line is the degree of cutting. On the 120° line the surface roughness value is 6.165µm, on the 240° line the surface roughness value is 6.105µm and on the 360° line the surface roughness value is 6.134µm. For the three measurement lines, an average surface roughness value of 6.135µm is obtained at the condition of the depth of cut a = 1 mm and the cutting time tc = 5.30 min.

Then in the investigation of the surface roughness value of the machining results of the AISI 1045 test material in the cutting conditions with the depth of cut, namely: a = 1.5 mm and the cutting time, namely: tc = 5.45 min, carried out in the machining conditions contained in Table 4. In the results of the surface roughness analysis of each axis axis in the analysis point area, as presented in Table 7 and Figure 11.

Tabel 7. Surface roughness value AISI 1045 cutting conditions 3

Coated Carbide Tool (TiAlN/TiN) PVD			**AISI 1045**
No.	**Line**	**Ra**	**Nilai**
1	120°	Ra_1	6.524
2	240º	Ra_2	6.473
3	360°	Ra_3	6.552
		$R\vec{a}$	**6.516**

Fig. 11. Surface roughness value at cutting condition 3 (v= 235 m/min|f= 0.1 mm/put|a=1.5 mm|t_c= 5.45 min)

As shown in Figure 11 in the cutting condition 3, the surface roughness value on each line is the degree of cutting. On the 120° line the surface roughness value is 6.524µm, on the 240° line the surface roughness value is 6.473µm and on the 360° line the surface roughness value is 6.552µm. For the three measurement lines, an average surface roughness value of 6.516µm is obtained at the condition of the depth of cut a = 1.5 mm and the cutting time tc = 5.45 min.

V. Conclusion

The results of research to obtain surface roughness (Ra) and optimum cutting conditions on dry machining of AISI 1045 materials using PVD coated carbide tools (TiAlN/TiN) as well as development with research design analysis of the results of student practicum processes in laboratories, especially laboratories related to material analysis including packaging surface, defects or flaws, lay, waviness and roughness are the answers to specific objectives, where the results of the analysis of these tests can be concluded as follows:

1. Cutting conditions 1: v= 235 m/min; f= 0.05 mm/put; a=0.5 mm and cutting time t_c= 5.23 min. On the 120° line the surface roughness value is 6.395µm, on the 240° line the surface roughness value is 6.395µm and on the 360° line the surface roughness value is 6.352µm. The average surface roughness value = 6.380µm.
2. Cutting conditions 2: v= 235 m/min; f= 0.75 mm/put; a=1 mm and cutting time t_c= 5.30 min. On the 120° line the surface roughness value is 6.165µm, on the 240° line the surface roughness value is 6.105µm and on the 360° line the surface roughness value is 6.134µm. The average surface roughness value = 6.135µm.
3. Cutting conditions 3: v= 235 m/min; f= 0.1 mm/put; a=1.5 mm and cutting time t_c= 5.45 min. On the 120° line the surface roughness value is 6.524µm, on the 240° line the surface roughness value is 6.473µm and on the 360° line the surface roughness value is 6.552µm. The average surface roughness value = 6.516µm.

Regarding the results of surface packaging testing to obtain the best surface roughness value at the optimum cutting conditions for dry machining AISI 1045 materials using coated carbide tools. From the 3 specified cutting conditions, it can be concluded that 2 cutting conditions have a cutting speed (v= 235 m/min); feed (f= 0.75 mm/put); depth of cut (a=1 mm) and cutting time tc= 5.30 min is the most optimum condition with an average value of surface roughness = 6.135µm.

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