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Experimental investigation of tool wear TiAlN(Al$_2$O$_3$)/TiN-coated carbide in the cam-shaft turning process

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Abstract

This research carried out experimental tests to determine the tool life and wear of Titanium Aluminum Nitride and Titanium Nitride-coated carbide tools (TiAlN/Al2O3 & TiN) during the hard facing process of cam shaft material turning. The results of this study will be used as a parameter for selecting carbide cutting tools in Teaching Factory (TEFA) activities. In the cutting process, the parameters used are VC = 36,74 m/min, f = 0,52 mm/rev, a = 0,2 mm, t = 460 min; and the cutting conditions are wet turning. The results showed that the TiAlN/ Al2O3-coated carbide tool experienced tool wear at the 100th minute with a VB value of 0,33 mm, while the TiN-coated carbide tool experienced tool wear at the 200th minute with a VB value of 0,30 mm. Theoretically, tool life for turning process conditions was analysed by graphical method in order to obtain the Taylor equation for TiAlN/Al2O3 coated carbide tools with an exponent value of n = 0,8 and a CT constant = 1.462,65 so that the Taylor tool life equation is V.Tn = CT ↔ V.T0,8 = 1.462,65. The results of the TiN carbide tool life test showed that the exponent n = 0,6 and CT constant = 882,59 so that the Taylor tool life equation is V.Tn = CT ↔ V.T0,6 = 882,59. Failure of TiAlN/Al2O3 and TiN-coated carbide tools on hard-processed cam shaft material cutting to face edge wear (VB), crater wear (KA), peeling of the tool material layer, and formation of built-up edge (BUE). The experimental test results of TiAlN/Al2O3 and TiN-coated carbide tools on the cutting of cam shaft material using a hard facing process show TiN carbide tools have a longer tool life than TiAlN/Al2O3, so they are recommended for Teaching Factory (TEFA) activities at Simas Berau Polytechnic

Keywords:
Carbide cutting tool, TiAlN/Al$_2$O$_3$ & TiN, tool life, side wear (VB), Taylor Equation

1 Introduction

Wear is generally defined as the progressive loss of material or the removal of an amount of material from one surface as a result of relative movement between that surface and another. Wear is not just one process, but several different processes that can take place independently or simultaneously. The wear mechanism is closely related to friction. Wear is not a basic property of the material but the material's response to the external system (surface contact). Any material, including cutting tools, can experience wear due to various mechanisms. The size of a grain or the diameter of the grain affects the strength of a material.

In the metal cutting industry, a carbide cutting tool with a coated-carbide type is one type of cutting tool that is commonly used in various sorts of machining processes. Tungsten Carbide (WC + Co) is the fundamental material for carbide cutting tool, which is coated with a coating material such as Titanium Nitride (TiN), Titanium Carbide (TiC), Titanium Carbonitride (TiCN), or Aluminum Oxide (Al$_2$O$_3$) [1]. Protective hard coatings grown by chemical vapor deposition (CVD) can mitigate against the thermal degradation of mechanical properties, in addition to further advantages that increase wear resistance and cutting performance. In particular, bilayer coatings of TiCN/α-Al$_2$O$_3$ are thermally stable during cutting, retain a superior hot-hardness, and have been instrumental in prolonging cutting tool life through the optimization of their crystallographic texture [2].

The tribological characteristics of the TiAlN layer have been the subject of several studies, where the influence of properties such as friction, hardness changes and oxide formation have been conducted [3][4]. Zheng et al observed chipping, cracks, adhesive, abrasive, oxidation, and diffusion wear of TiAlN/TiN PVD coated cutting tools in hard turning of high strength steel. A protective layer of Si–O and Ti–O was found to reduce the friction coefficient [5]. Wang et al, observed that the sticking and sliding areas increase with increasing cutting speed and hence temperature when using TiAlN coatings in turning of Ti-alloys. The crater wear was considered to affect the cutting performance more than flank wear [6].

Saobi et al, investigated the wear mechanism of PCBN with PVD coating and without PVD coating on hardened steel 16MnCr5. The increase in wear resistance of TiAlN coating is mainly attributed to its improved mechanical properties resulting from coherent isostructural spinodal decomposition and hardening that occurs under the action of high applied cutting stress, The AlCrN coating, despite its superior oxidation resistance to the other coating material systems and high hardness, displays a lower crater and flank wear resistance [7]. The application of coatings to the cutting tools has promoted a significant improvement in the behaviour of tools, allowing for higher performance, greater productivity, and longer tool life [8]. Many coatings have been tested, as well as different combinations of them, taking advantage of the benefits of each one. Moreover, some coatings still have the flexibility of being deposited through the techniques of PVD or CVD, which also influences the coating's properties and machining performance. The coatings have been tested mainly in the machining of difficult-to-cut materials such as titanium alloys, nickel alloys, pre-treated steels, and duplex stainless steels [9], [10]. Halim et al, reported the spindle rotation rate and cutting depth as well as wet and dry turning methods affect the surface hardness of the material [11].

Michailidis studied the milling of the Ti6Al4V titanium alloy with tungsten carbide tools coated with PVD AlTiN, comparing its behavior with the same uncoated tool [12]. Sunarto et al, reported the ability of TiAlN and TiN coatings on the cutting process of 6061 aluminum alloy under dry conditions and high cutting speeds. The magnitude of the cutting speed is directly proportional to the growth of side wear (VB) [13]. Lai et al, used several compositions of the same coating to analyses which type of lubrication could be more suitable and sustainable when cutting AISI 316L stainless steel. Some of the coating compositions used to cover the WC-Co tool substrates included Si and Cr, in addition to Al, Ti and N [14]. Da Silva et al, also investigated the behavior of cemented carbide tools coated with a single layer of TiAlN in dry and wet machining of AISI 1047 steel. Longer tool life was reported when a low lubrication flow was used. In the dry machining condition, the chipping phenomenon was verified. The worst results in terms of longevity of tool life were obtained when lower cutting speeds were used [15].

According to the characterization of tool failure presented above, the tool wear effect in terms of technical performance measures is related to the consequences of decreased accuracy dimensions, increased surface roughness, increased cutting force, increased temperature, and vibration increases. Based on this problem, it is necessary that further research be conducted with variables that are mainly related to tool life and material. The purpose of this research is to determine the tool life of carbide cutting coated with Titanium Aluminum Nitride (TiAlN) and Titanium Nitride (TiN). These materials will be used in Teaching Factory (TEFA) activities, so the results of this study provide parameters for operators in the machining process.

2 Mechanism of Tool Wear

Based on the research results, tool wear and damage are dominant factors or a combination of certain factors. These causative factors are: Abrasive process, Chemical process, Adhesion process, Oxidation process, Plastic deformation and, Cracking and fatigue.

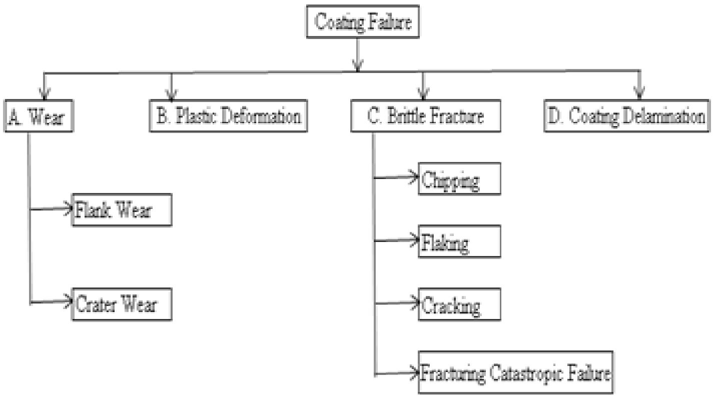


Fig.. 1. Tool failure spectrum diagram

2.1 Cutting Tool Life

Tool wear will increase with increasing cutting time. At a certain time, the relevant tool can no longer be used. The more the tool wears, the more critical the tool's condition becomes. If the tool is still used, the rate of wear will increase, and finally the tip of the tool will be damaged.

By specifying the criteria when it runs out. If the tool life as above is deemed unusable, then the tool life can be determined, i.e., starting with a new tool (after the cutting tool has been sharpened or the insert has been replaced). The tool life dimension can be a measure of time, which can be calculated directly or indirectly by correlating to other quantities. This is intended to simplify the calculation procedure according to the type of work performed.(Fig. 2)

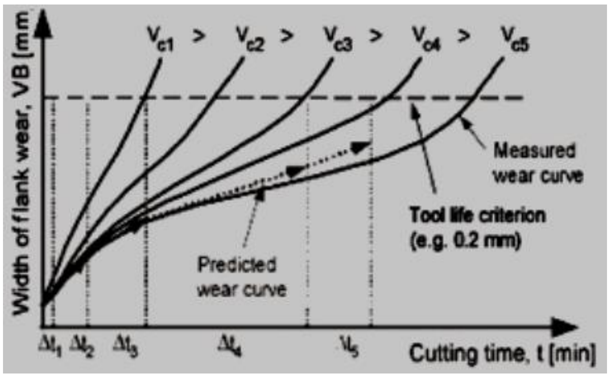


Fig. 2. Growth of Edge Wear and Cutting Speed [16]

The equation showing the relationship between cutting speed and tool life was first proposed by F. W. Taylor in 1907. For a constant value for the dimensional limit of wear as well as a certain combination of tool and workpiece, the equation is as follows:

$$V.T^n = C_T$$

Where :

C_T = Taylor tool life constant is equivalent to cutting speed for 1 minute of tool life.
V = Cutting speed
n = The exponential value, is the slope of a linear functionn = tan = y/x

3 Materials and Methods

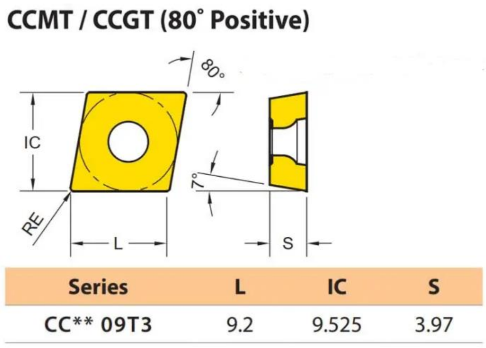
In this research, experimental methods are used directly on the object to be studied. This method is used to directly determine the damage to the carbide cutting tool as a result of the process of cutting material with wet turning, which has been carried out by the hard facing process.

3.1 Materials

a. The workpiece material used in this study is a cam shaft which has been hard faced using RB-26 electrodes. It has a length of 1000 mm and a diameter of 38 mm.
b. The carbide insert used in this research is a carbide insert type CCMT09T304-UG PVD TiAlN/ Al_2O_3 and CCMT09T308-PSF AH725 PVD TiN. It has a 0.8 mm tool nose radius (r), 3.97 mm thickness (s), and negative 80° cutting tip.
c. The conventional lathe machine used in this research is the Krisbow KW15-979. This lathe machine has 1.5KW power, 1400r/min and 2000 RPM max spindle speed capacities, which is located at the Simas Berau Polytechnic workshop.
d. The measuring instrument used to measure the edge wear length (VB) is Microscope Series MIT 300/500.
As shows fig. 3,4, and 5

(a) (b)

Fig. 3. Insert carbide TiN(a) and TiAlN/Al_2O_3(b)



Series	L	IC	S
CC** 09T3	9.2	9.525	3.97

Fig. 4. Dimensions of the Carbide Cutting Tool

Material cam shaft which has been hard faced using RB-26 electrodes (Fig. 5).

Fig. 5. Material cam shaft which has been hard faced using RB-26 electrodes

Table 1. Chemical composition and properties of the coating material systems (mechanical properties are given as typical values obtained for the coatings in the as-deposited state on cemented carbide substrates) [18].

Coating Material Variant	TiN	$TiAlN/Al_2O_3$
Composition	TiN	$Ti_{0.34}Al_{0.66}N$
Coating Thickness (µm)	2.0	1.8
Hardness (GPa)	28	29
Young Modulus (GPa)	530	530
Residual Stress (GPa)	-4.2 ± 0.7	-1.4 ± 0.2

3.2 Methods

This research, an experimental method was used to observe carbide tool wear using the following procedure:

a. Cutting cam shaft material with a cutting speed (Vc) of 36.74 m/min, feed rate (f) of 0.52 mm/rev, depth of cut (a) of 0.2 mm, and a cutting time of 460 min with an edge wear measurement time (VB) at each 20 min interval..
b. Wear on the carbide tool after testing is observed using a microscope.
c. To determine the wear value of the carbide insert cutting, macro photos were taken using the MIT 300/500 Series Microscope instrument, which was carried out at the Machining Laboratory of the Simas Berau Polytechnic
d. The results of the macro photos are then discussed and analysed to obtain conclusions about tool damage as an effect of the hard facing material treatment.

4 Results and Discussion.

To determine the wear value of the carbide insert cutting, macro photos were taken using the MIT 300/500 Series Microscope instrument, which was carried out at the Machining Laboratory of the Simas Berau Polytechnic. The results of the macro photos are then analysed using Image-J software to determine the wear value. From the experimental tests carried out, it is obtained that the cutting conditions provide optimal tool life for the carbide tool.

4.1 Edge Wear (VB)

Tool life is the entire cutting time (tc) until the specified wear limit is reached (Vbmax = 0.2 to 0.6 mm) at a cutting time of not less than 5 minutes [19]. Wear measurement cutting tools (VB) (Table 2).

Based on Fig. 6, shows the edge wear value (VB) on the $TiAlN/Al_2O_3$ carbide insert tool reaches the maximum wear value at the 100th minute with a VB value of 0.33 mm, while the TiN carbide insert tool reaches the maximum wear value at the 200th minute with a VB value of 0.30 mm. Carbide cutting tool edge wear increases with the length of cutting time. The TiN carbide insert tool edge wear rate is slower than the $TiAlN/Al_2O_3$ carbide tool edge wear. This occurs due to several factors, including feed rate, shock loads, and cutting temperature in the contact area. From the analysis of table 2 and fig. 6, it can be concluded that TiN carbide insert tools have better wear resistance than $TiAlN/Al_2O_3$, this is because the titanium nitride (TiN) coating has lubricating properties that reduce friction between the cutting insert and the workpiece, thereby preventing temperature increases at higher cutting speeds and consequently slowing the growth of tool wear [17].

Table 2. Wear measurement cutting tools (VB)

No	Time (Min)	TiAlN/Al2O3 (mm)	TiN(mm)
1	20	0.106	0.041
2	40	0.181	0.061
3	60	0.191	0.071
4	80	0.277	0.087
5	100	0.33	0.128
6	120	0.457	0.133
7	140	0.553	0.194
8	160	0.564	0.24
9	180	0.66	0.255
10	200	0.766	0.301
11	220	0.84	0.301
12	240	0.883	0.357
13	260	1.000	0.418
14	280	1.096	0.48
15	300	1.202	0.515
16	320	1.234	0.531
17	340	1.362	0.577
18	360	1.372	0.582
19	380	1.426	0.622
20	400	1.511	0.633
21	420	1.521	0.684
22	440	1.564	0.719
23	460	1.585	0.745

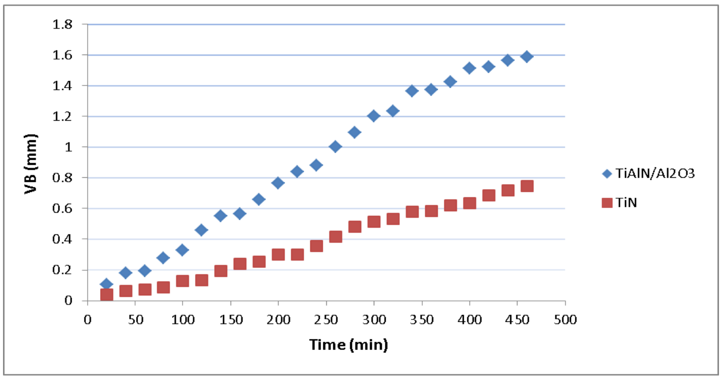


Fig. 6. Edge wear growth curve (VB)

4.2 Exponent n and C_T of Taylor's Tool Life

The wear dimension is the basis for determining the tool life limit. Accordingly, the rate of wear growth determines the end of the cutting tool life. Tool life can be predicted by the Taylor Equation (eq.1)

$$V.T^n = C_T \tag{1}$$

The tool life can be predicted by empirical calculations by using the Taylor tool life equation. From the test results will be obtained a graph of the relationship between the tool life of the cutting tool and cutting speed. From the data, a double logarithm graph is made and the tool life can be considered as a function of cutting speed then a trendline is made to assume the power of the cutting tools, as shown in fig. 7.

n and the **C_T** constant can be analyzed by graphical methods to determine the value of the exponent. From the graph, it can be seen that the slope of the exponential value of n is obtained from the slope of the graph where n = tan α, or the comparison of y/x values, and the C_T constant can be obtained by extrapolating n at T

= 1 min, which is the linear extension of n. From this analysis, the value of the exponent n and the constant C_T will be obtained.

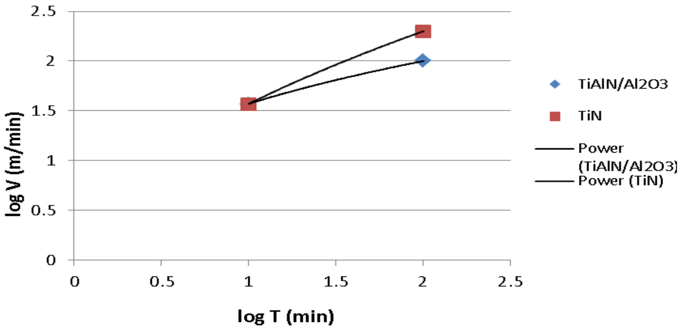


Fig. 7. Carbide Tool Wear Rate Curve to Determine the Value of **n** and **C_T** (Taylor Equation)

The experimental test results for TiAlN/Al_2O_3 carbide tool life, the exponent value n = 0,8 and the C_T constant = 1.462,65 so the tool life equation $\mathbf{V.T^{0,8} = 1.462,65}$. While the experimental test results for TiN carbide tool life, the exponent value n = 0,6 and the C_T constant = 882,59 so the tool life equation $\mathbf{V.T^{0,6} = 882,59}$.

4.3 Wear Characteristic of TiAlN/Al_2O_3 Carbide Insert Cutting Tools

The wear and tear that occurs on the TiAlN/Al_2O_3 carbide insert tool can be seen in fig. 8.

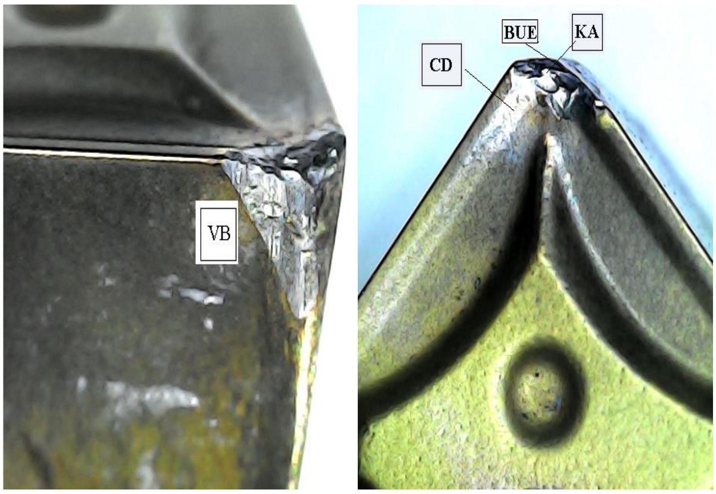


Fig. 8. Wear Characteristic of TiAlN/Al_2O_3 Carbide Insert Cutting Tools

Fig. 8 shows that there is failure to the edge wear (VB), crater wear (KA), peeling of the tool material layer (CD) and the formation of built-up edge (BUE), which is attached along the cutting edge of the tool and can affect the tool geometry. This is because the BUE is a dynamic structure, and during the cutting process the BUE will grow, and this is due to the presence of adhesion forces. This adhesion force causes chip accumulation on the cutting edge [20].

4.4 Wear Characteristic of TiN Carbide Insert Cutting Tools

The wear and tear that occurs on the TiN carbide insert tool can be seen in fig. 9. Fig. 9 shows that there is failure at the edge wear (VB), crater wear (KA), and the formation of a built-up edge (BUE) that sticks along the cutting edge of the tool and can affect tool geometry. BUE is a dynamic structure that can be completely peeled off when there is a shock load so as to carry some of the outermost layer of the tool. At low cutting speeds, an abrasive process also occurs which rubs against the main plane surface.

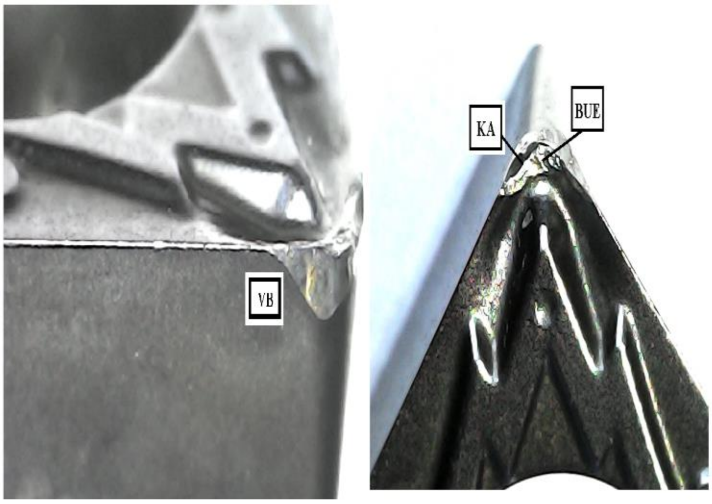
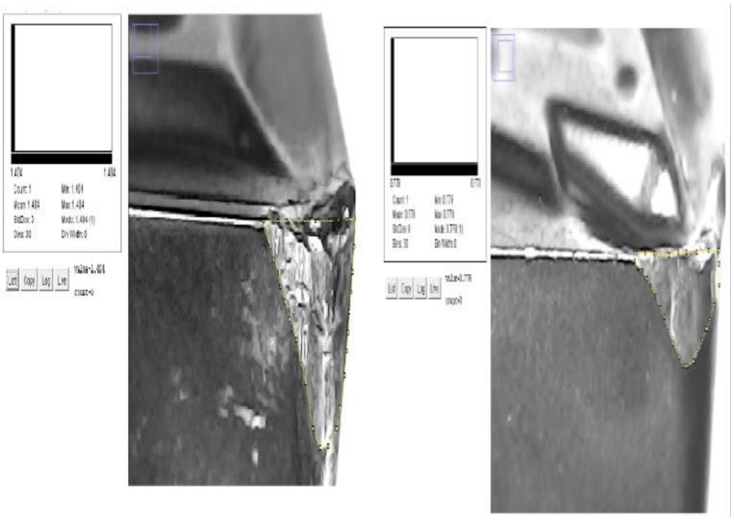


Fig. 9. Wear Characteristic of TiN Carbide Insert Cutting Tools

4.5 Areas of Edge Wear (VB)

Fig. 10 shows the edge wear area (VB) that occurs on the TiAlN/Al_2O_3 carbide insert tool with a cutting time of 460 minutes is 1.404 mm², whereas the TiN carbide insert tool with the same cutting conditions has an edge wear area (VB) of 0.778 mm².



(a) (b)

Fig. 10. Edge Wear Area on Carbide Cutting Tool (a) TiAlN/$Al_2O_3$and (b) TiN

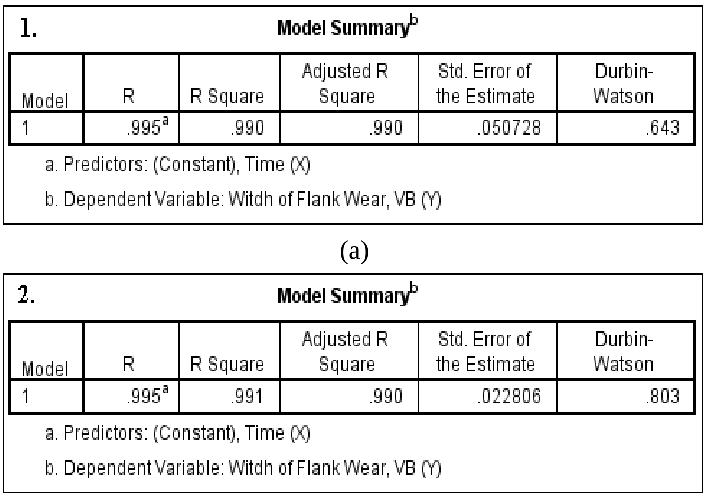
4.6 Regression Model Approach

The regression equation is used to obtain data using a mathematical model approach. This regression analysis is useful for determining the best interpretation of a group of variables and the response. Based on the findings of the study of two factors, namely the cutting time factor and the type of carbide insert used, TiAlN/Al_2O_3 and TiN on the edge wear rate with four samples of the test object and 23 observations, the following response results were obtained.

Fig. 11 shows the R value (Pearson Correlation) in the experimental test of TiAlN/ Al_2O_3 and TiN carbide cutting tools. This shows a simple correlation between the X variable and Y. The R value is 0.995, meaning that the correlation between the time variable and edge wear is 0.995. This means that there is a close relationship because the value is close to 1.

Furthermore, the value of R Square (R^2) shows the coefficient of determination, which shows the percentage contribution of the effect of the independent variable on the dependent variable. On the TiAlN/Al_2O_3 carbide cutting tools, the R^2 value is 0.990, which means that the percentage contribution of the influence of the time variable to the edge wear value is 99%. For the TiN, the

R^2 value is 0.991, meaning that the percentage of the contribution of the influence of the time variable on the edge wear value is 99.1%.



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Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.995^a	.990	.990	.050728	.643

a. Predictors: (Constant), Time (X)

b. Dependent Variable: Witdh of Flank Wear, VB (Y)

(a)

2\.

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.995^a	.991	.990	.022806	.803

a. Predictors: (Constant), Time (X)

b. Dependent Variable: Witdh of Flank Wear, VB (Y)

(b)

Fig. 11. Output model summary carbide cutting tool (a) $TiAlN/Al_2O_3$ and (b) TiN.

Fig. 12 shows that the Standardized Coefficient value on $TiAlN/Al_2O_3$ and TiN carbide tools, the Beta coefficient value of 0,995 is close to 1, which means that the relationship between the X variable (time) and the Y variable (VB) is getting stronger.

The regression equation for simple linear regression is in eq.2:

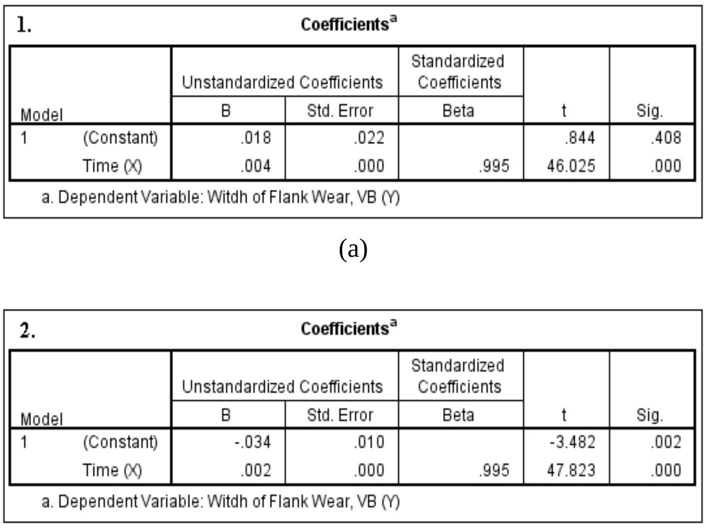
$$Y' = a + bX \qquad (2)$$

For $TiAlN/Al_2O_3$ carbide tools, the regression equation is obtained (eq.3):

$$Y' = 0{,}018 + 0{,}004X \qquad (3)$$

Furthermore, for the TiN carbide tool, the regression equation is obtained (eq.4):

$$Y' = -0{,}034 + 0{,}002X \qquad (4)$$



1\.

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.018	.022		.844	.408
	Time (X)	.004	.000	.995	46.025	.000

a. Dependent Variable: Witdh of Flank Wear, VB (Y)

(a)

2\.

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.034	.010		-3.482	.002
	Time (X)	.002	.000	.995	47.823	.000

a. Dependent Variable: Witdh of Flank Wear, VB (Y)

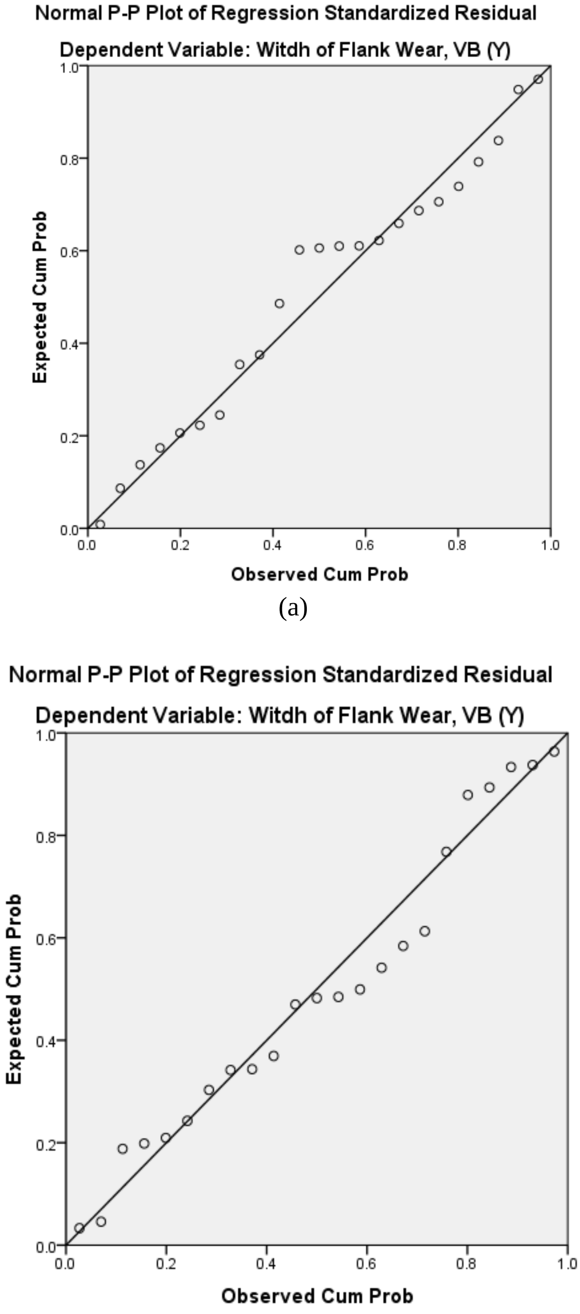
(b)

Fig. 12. Output Coefficients Carbide Cutting Tool (a) $TiAlN/Al_2O_3$ and (b) TiN

4.7 The Residual Normality Test

The residual normality test is used to test whether the residual value resulting from the regression is normally distributed or not. A good regression model has a normally distributed residual value. The method used is the graphical method, by observing the spread of data on diagonal sources on the Normal P-P Plot of regression standardized graph.

The results of the normality test of $TiAlN/Al_2O_3$ and TiN carbide tools are shown in fig. 13. The output graph below explains that the points are spread around the line and follow the diagonal line, so the residual value is normally distributed.



(b)

Fig. 13. Output graph of the normality test results for the residual carbide cutting tool (a) $TiAlN/Al_2O_3$ and (b) TiN

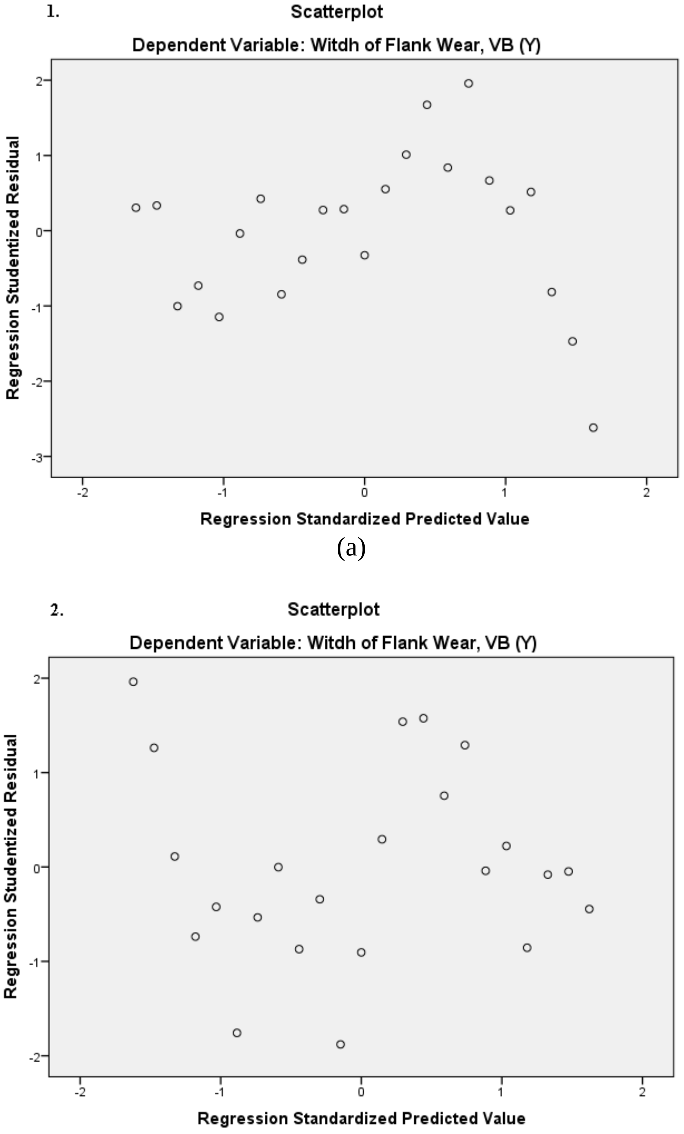
4.8 Heteroscedasticity Test

Heteroscedasticity is the residual variance that is not the same in all observations in the regression model. In a good regression, there should be no heteroscedasticity. The following is a heteroscedasticity test using the graph method by observing the pattern of dots on the regression graph.

The basic criteria for decision-making are as follows [21] :

1. If there is a certain pattern, such as dots that form a regular pattern (wavy, wide, and then narrow), then heteroscedasticity occurs.
2. If there is no clear pattern, such as the dots spread above and below the value of 0 on the Y axis, then there is no heteroscedasticity.

The results of the heteroscedasticity test are shown in the output of the regression results in fig. 14. From the output below, it can be seen that the points do not form a clear pattern, and the points spread above and below the value of 0 on the Y axis, so it can be concluded that there is no heteroscedasticity in the regression model.



(a)

(b)

Fig. 14. Output graph of heteroscedasticity test carbide cutting tool (a) TiAlN/Al_2O_3 (1) and (b) TiN

5 Conclusions

According to the experimental test results of TiAlN/Al_2O_3 and TiN-coated carbide cutting tools on cam shaft material cutting using a hard facing process, the TiN carbide insert tool has better wear resistance than the TiAlN/Al_2O_3 carbide cutting tool. The tool life limit is determined by the wear dimension, so the rate of wear growth determines the end of the tool life.

Taylor's tool life equation yields the exponent value n = 0,8 and the C_T constant = 1.462,65 for tool life testing of TiAlN/Al_2O_3 carbide tools. $\mathbf{V.T^n = C_T \leftrightarrow V.T^{0,8} = 1.462,65}$ is the Taylor tool life equation. While testing the TiN carbide tool life, the exponent value of n = 0,6 and the C_T constant = 882,59 were obtained. $\mathbf{V.T^n = CT \leftrightarrow V.T^{0,6} = 882,59}$ is the Taylor tool life equation.

The experimental test results of TiAlN/Al_2O_3 and TiN-coated carbide tools on the cutting of cam shaft material using a hard facing process show damage to edge wear (VB), crater wear (KA), peeling of the tool material layer (Coating Delamination), and the formation of built-up edge (BUE), which adheres along the cutting edge of the tool and can affect tool geometry.

The experimental test results of TiAlN/Al_2O_3 and TiN-coated carbide tools on the cutting of cam shaft material using a hard facing process show TiN carbide tools have a longer tool life than TiAlN/Al_2O_3, so they are recommended for Teaching Factory (TEFA) activities at Simas Berau Polytechnic.

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