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MECHANICAL PROPERTIES AND CUTTING PERFORMANCE OF ELECTROLESS TERNARY NI-W-P COATED CUTTING TOOLS

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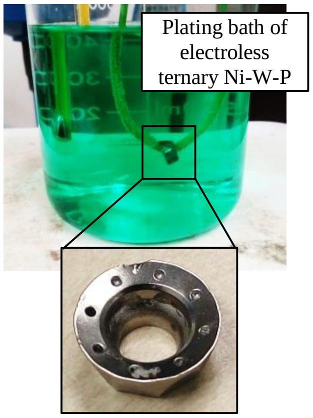
Graphical abstract



Abstract

This paper presents a new approach of electroless nickel deposition (END) on cutting tools as to enhance tool performance. END involves several reactions in aqueous solution and is performed without using electrical power. The cutting performance of electroless ternary Ni-W-P alloy-coated cutting tools that were prepared in plating baths with different pH levels and with the addition of heat treatment was investigated. The cutting tool life was evaluated during machining on AISI D2 steel followed by measurement of surface roughness. Experimental results showed that END cutting tools produced from a plating bath with a pH of 8.5 with heat treatment resulted in the longest tool life, which was 7 minutes 32 seconds, and the lowest surface roughness, which was 0.412 µm. High deposition rate and high thickness of coating obtained under such pH condition were found to be the main factors in enhancing tool life. Furthermore, the addition of heat treatment increases the hardness and improves the coating surface.

Keywords: Electroless nickel deposition (END), electroless ternary N-W-P alloy coating, heat treatment, tool life, surface roughness

1.0 INTRODUCTION

As to survive during challenging market demand, many manufacturing industries are trying to decrease their machining costs and improve the quality of machined parts. There is number of studies that associated with coating of cutting tool as to prolong the cutter performance [1-3]. One of the approaches in improving cutting performance is by depositing a single or multi-layer of hard material coating on cutting tool substrate which widely applied on tungsten carbide (WC) [4]. The coated cutting tool shows lower friction than uncoated cutting tool hence reduce thermal generation and cutting force especially at the chip-cutting tool interface [5]. Physical vapour deposition (PVD) and chemical vapour deposition (CVD) are two of the well-known coating techniques that are widely used in manufacturing coated cutting tools but they are comparatively expensive to install and require skilled operators [6].

Normally, the cutting tool was coated by mean of PVD and CVD. However, electroless nickel deposition (END) is less to be reported. This coating method involves several reactions in aqueous solution without using electrical power [7]. Normally, END process is performed by depositing a layer of nickel-phosphorus alloy on a metal, where it depends on sodium hypophosphite dihydrate ($NaH_2PO_2{\cdot}2H_2O$) as a reducing agent to react with metal ions for deposition on metal [7]. END offers advantages over coating features, such as producing a uniform coating layer, and its resistance to wear, friction and corrosion, and it is also a cost-effective process [8-10]. Moreover, a study on ternary Ni-W-P alloy in END process showed that it also can be useful for other mechanical properties of coatings [11]. Initially, END has been practiced in many engineering applications such as aerospace, automotive, chemical and food processing industries [12] but its implementation on cutting tools is still limited. Because of the advantages and feasibility of END, it was recommended to be applied in cutting tool since the process is simple and can be rebuilt on the worn area. However, the process requires the inclusion of heat treatment as to increase the coating hardness as high as 1100 Hv [13].

This research aims to investigate the cutting performance of electroless ternary Ni-W-P alloy-coated cutting tools that were prepared in plating baths with different pH levels and with the addition of heat treatment. The cutting performance was evaluated by machining them on AISI D2 steel followed by measurement of the tool life and surface roughness of each cutting tool.

2.0 METHODOLOGY

2.1 Preparation of END Coated Cutting Tool

Figure 1 shows the process of coating cutting tool with electroless ternary Ni-W-P alloy. A 10 mm diameter of uncoated tungsten carbide insert (QPMT 10T335 PPEN) with hardness of 1630 Hv was used as a substrate in the electroless deposition process. The composition of plating bath and operating condition are described in Table 1. The electroless ternary Ni-W-P alloy was deposited on the tungsten carbide insert in an acidic plating bath (pH 4.75) or alkaline plating bath (pH 8.50) for 1 hour at a temperature of 358±2 K. Then, heat treatment was applied to each ternary nickel alloy for 1 hour at a temperature of 623 K. A total of 4 types of samples were produced. Table 2 summarizes the specimens to be analysed on cutting performance.

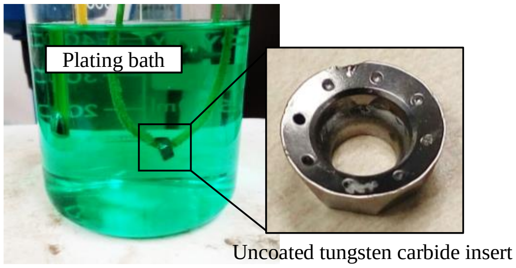


Figure 1 Electroless deposition process of ternary Ni-W-P alloy

2.2 Evaluation of Cutting Performance

The cutting performance of each sample was evaluated by performing a cutting process on AISI D2 steel. The cutting parameters to be used in this experiment are described in Table 3. The machining experiment was conducted using a CNC milling machine under dry condition. The tool life of each cutting tool was determined by measuring flank wear on cutting edge throughout the experiment. The process was continued until the flank wear reached 0.3 mm, which is considered as tool failure [14]. The machining time was recorded as to observe the tool life under specific cutting condition. As to observe the relationship between the tool life and surface finish, the surface roughness of the machined part was measured by portable surface roughness tester (Mitutoyo Corp.: Surftest SJ-301).

Table 1 Plating bath composition and condition

Plating Bath Component	
Nickel Sulphate Hexahydrate ($NiSO_4 \cdot 6H_2O$)	0.10 M
Sodium Hypophosphite Dihydrate ($NaH_2PO_2 \cdot 2H_2O$)	0.28 M
Trisodium Citrate Dihydrate ($Na_3C_6H_5O_7 \cdot 2H_2O$)	0.20 M
Ammonium Sulphate $(NH_4)_2SO_4$	0.50 M
Sodium Tungstate Dihydrate ($NaWO_4 \cdot 2H_2O$)	0.01 M
Operation Condition	
Bath temperature [K]	358±2
Deposition time [s]	3600

Table 2 Samples of END coated tools

Sample Name	Plating Bath pH	Heat Treatment Condition
T-pH4.75	4.75	-
T-pH4.75-HT	4.75	623 K for 1 hour
T-pH8.50	8.50	-
T-pH8.50-HT	8.50	623 K for 1 hour
Uncoated (for comparison)	-	-

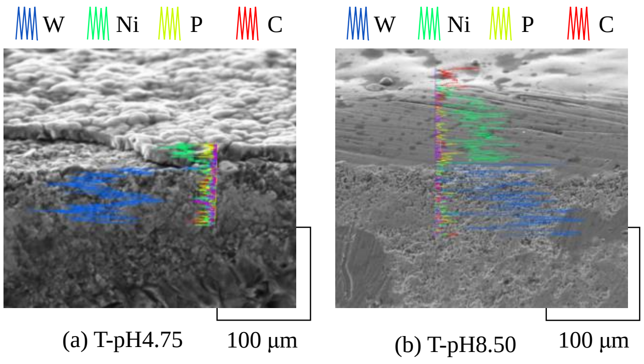
Table 3 Cutting conditions

Cutting speed v	125 m/min
Feed rate f	0.08 mm/tooth
Axial depth of cut d_A	1.5 mm
Radial depth of cut d_R	2.5 mm
Workpiece	AISI D2 Steel
Environment	Dry cutting

3.0 RESULTS AND DISCUSSION

3.1 Mechanical Properties

The result of the experiment shows the electroless ternary Ni-W-P alloy was successfully deposited on the tungsten carbide inserts in acidic and alkaline plating baths. Figure 2 shows the cross-sections of both samples and the coating thickness were measured from the line scan analysis. The rate of deposition, coating thickness and hardness of coated tools deposited in acidic and alkaline plating baths were ranged between 5.6 – 19.6 µm/hr, 10 – 60 µm, 638 – 858 Hv, respectively as shown in Figure 3. The deposition rate and the coating thickness were high when the END process was performed in the alkaline plating bath with 19.6 µm/hr and 60 µm, respectively. On the other hand, the highest hardness of 858 Hv was obtained by the tool deposited in the acidic plating.



(a) T-pH4.75 (b) T-pH8.50

Figure 2 SEM line scan analysis of cross-section

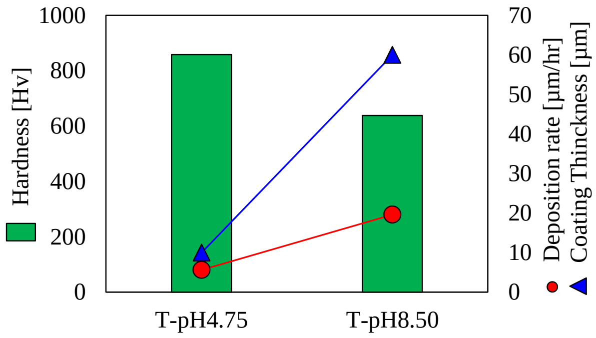


Figure 3 Hardness, deposition rate and thickness of coatings

Heat treatment was carried out for both conditions. The hardness after heat treatment was found to be increased by 10% and this was due to the increment of crystallinity from the segregation of elements [15]. However, there was no significant change in the coating thickness after the heat treatment on both samples.

3.2 Tool Life

Figure 4 shows the tool wear progression for each coated cutting tool. Each sample was machined until the tool wear reached 0.3 mm. From the graph, it was found that the samples produced in the acidic plating bath, T-pH4.75 and T-pH4.75-HT resulted in shorter tool life than the uncoated tool by 2 minutes. The sample produced in the alkaline plating bath without heat treatment, T-pH8.50 can be last for only about 57 seconds. Coated tool produced in the alkaline plating bath with heat treatment recorded as the longest tool life, which was 7 minutes 32 seconds. It shows that the coated cutting tool improved by about 40% of tool life compared to the uncoated cutting tool.

Figure 5 shows the comparison of wear rate between the cutting tool T-pH8.50-HT and other coated carbide tools which were coated with CVD and PVD. It was found that PVD has the lowest wear rate followed by T-pH8.50-HT, CVD and the uncoated tool. Among these coated tools, PVD has the superior hardness, and as the previous result indicated that the heat treatment addition on END coated tool has increased the layer hardness by about 10%. This result indicated that the electroless ternary Ni-W-P alloy-coated cutting tool is competitive with other coating processes.

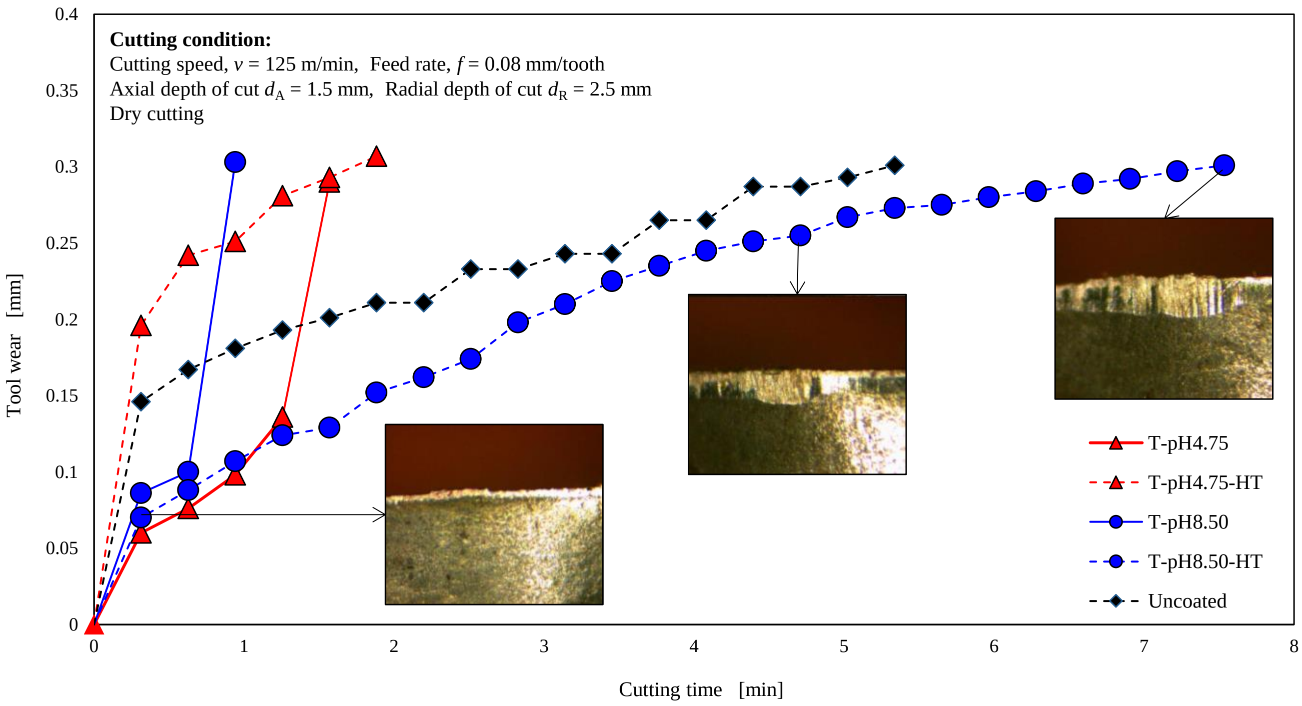


Figure 4 Tool wear progression of electroless ternary Ni-W-P alloy-coated cutting tool

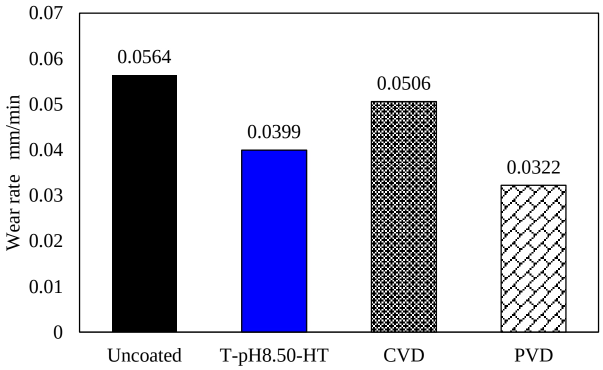


Figure 5 Comparison of wear rate

3.3 Surface Roughness

Figure 6 shows the average surface roughness of electroless ternary Ni-W-P alloy-coated cutting tools and an uncoated tool. From the graph, it can be seen that the average surface roughness of the samples produced in the acidic plating bath, T-pH4.75 and T-pH4.75-HT, was slightly higher than that of the uncoated tool, whereas the cutting tool deposited in the alkaline plating bath without heat treatment, T-pH8.50, had the highest average surface roughness. Furthermore, T-pH8.50-HT had the smallest average surface roughness, which was 0.412 µm. The surface roughness of AISI D2 steel improved by about 27% when machined using a heat-treated coated tool deposited in a plating bath with a pH of 8.50. It was understood that the heat treatment of electroless ternary Ni-W-P alloy deposited in a plating bath with a pH of 8.50 produced a smoother surface compared to the previous heat treatment [15].

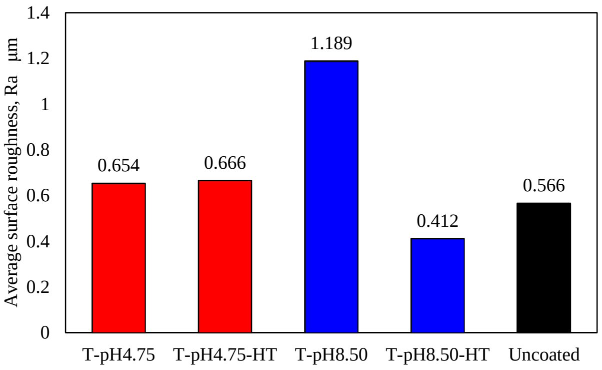


Figure 6 Average surface roughness of samples.

4.0 CONCLUSION

The cutting performance of electroless ternary Ni-W-P alloy-coated cutting tools produced in acidic and alkaline plating baths was experimentally investigated. The conclusion can be rendered as follows:

1. Electroless ternary Ni-W-P alloy-coated cutting tools prepared using an alkaline plating bath (pH 8.50) produced higher coating thickness than tools prepared in an acidic plating bath (pH 4.75) and the implementation of heat treatment increased the hardness by about 10%.
2. Electroless ternary Ni-W-P alloy-coated cutting tools prepared in a plating bath with a pH of 8.50 with heat treatment resulted in the highest tool life, which was 7 minutes 32 seconds. The tool life increased by about 40% compared to the uncoated cutting tool.
3. Electroless ternary Ni-W-P alloy-coated cutting tools prepared in a plating bath with a pH of 8.50 of with heat treatment resulted in the lowest surface roughness, which was 0.412 µm. This was influenced by the smoother surface of the coated layer produced after the heat treatment.

Acknowledgement

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References

[1] Stephenson, D. A. and Agapiou, J. S. 2016. *Metal Cutting Theory and Practice*. Third Edition. CRC Press.

[2] Bouzakis, K. D., Michailidis, N., Skordaris, G., Bouzakis, E., Biermann, D., and M'Saoubi, R. 2012. Cutting With Coated Tools: Coating Technologies, Characterization Methods and Performance Optimization. *CIRP Annals-Manufacturing Technology*. 61(2): 703-723.

[3] Suresh, R., Basavarajappa, S. and Samuel, G. L. 2012. Some Studies on Hard Turning of AISI 4340 Steel Using Multilayer Coated Carbide Tool. *Measurement*. 45(7): 1872-1884.

[4] PalDey, S. C. D. S. and Deevi, S. C. 2003. Single layer and Multilayer Wear Resistant Coatings of (Ti,Al)N: A Review. *Materials Science and Engineering: A*. 342(1): 58-79.

[5] Schintlmeister, W., Wallgram, W., Kanz, J. and Gigl, K. 1984. Cutting Tool Materials Coated by Chemical Vapour Deposition. *Wear*. 100(1): 153-169.

[6] Kennedy, D. 2008. Exploitation of Surface Engineering Technology Research. *Proc. of International Conference, Matrib Materials, Tribology and Processing*. Croatia.

[7] Mallory, G. O. and Hajdu, J. B. 1990. *Electroless Plating: Fundamentals and Applications*. William Andrew.

[8] Loto, C. A. 2016. Electroless Nickel Plating–A Review. *Silicon*. 1-10.

[9] Navinšek, B., Panjan, P. and Milošev, I. 1999. PVD Coatings as an Environmentally Clean Alternative to Electroplating and Electroless Processes. *Surface and Coatings Technology*. 116: 476-487.

[10] Schlesinger, M. 2000. Electroless Deposition of Nickel. *Modern Electroplating*. 4: 667-684.

[11] Shu, X., Wang, Y., Lu, X., Liu, C. and Gao, W. 2015. Parameter Optimization for Electroless Ni–W–P Coating. *Surface and Coatings Technology*. 276: 195-201.

[12] Mallory, G.O. and Hajdu, J.B. 1990. *Electroless Plating: Fundamentals and Applications*. William Andrew.

[13] Davis, J. R. ed. 1995. *ASM Specialty Handbook: Tool Materials*. ASM international. 388.

[14] Standard, I. S. O. 8688-2.1989. *Tool Life Testing in Milling - Part 2: End Milling*.

[15] Azran, M. N., Hamzah, Z., Zaimi, M., Aziz, M. S. A., Lau, K. T., Kasim, M. S., Azam, M. A. and Anand, T. 2015. Effect of Heat Treatment on Various Electroless Ternary Nickel Alloy Deposition Corrosion Behavior in 3.5wt% NaCl Solutions. *Proc. of International Conference on Design and Concurrent Engineering (iDECON 2015).*