Characterization of Nickel-Cubic Boron Nitride Coating via Electroless Nickel Deposition on High Speed Steel and Carbide Substrates

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Abstract. Ceramic-metal surface coating is very well known for its high thermal, wear and corrosion resistance. The paper discussed on comparison of characterization of Nickel-cubic boron nitride (Ni-CBN) composite coating on two types of substrate. The substrates used are High Speed Steel (HSS) and Carbide due to good hardness, low cost and easily available. The composite Ni-CBN has been used in machining industries recently. It is desirable to get high ceramic of CBN to metal Ni ratio for corrosion, thermal and wear resistance. A sample of HSS and carbide substrate of CBN was used as the base for composite deposition. The surface coating of Ni-CBN was deposited via electroless nickel where the process of involved chemical reactions as the ceramic CBN powders was embedded within the coating. The characterization of the composite deposition was done by JSM-7800F Field Emission Scanning Electron Microscope (FESEM) coupled with Energy Dispersive X-Ray (EDX). The FESEM image proves that nano CBN powders were embedded in HSS substrate and distributed consistently on the coating surface.

1. Introduction

Electroless nickel (EN) coating is a method in which a nickel alloy is deposited on a metal surface via a chemical reaction. Different with nickel electroplating, electroless nickel plating does not need a power source to produce the deposit. The electroless nickel coating decrease the effects of corrosion and wear, which can encompass the suitable life of cutting tools and workpiece. A broad growing market of coated cutting tools has been developed. Many experts and researchers evolving coatings expertise base on the appearance of new materials, cutting tools and film materials, and the evolution method of coatings description, and the continuous requirement for high production rates for industry consumption. With a thickness of fewer than 10 μm, this electroless nickel process has exceptional standardization and impenetrable deposition \cite{1}. The process of electroless deposition has been widely practiced in manufacturing with the best established coating propositions tremendous corrosion, lubricity, ductility, wear and abrasion resistance, high hardness, and electrical properties \cite{2}.

This integration on elements in the electroless process deposit has remained extensively explored and contain the combination of silicon carbide, diamond, silicon oxide, silicon nitride, boron carbide, alumina, ceria, zirconia, and yttria particles \cite{3-4}.

The cutting tool’s thermal property of the material such as thermal conductivity is the finest significant representative in hard milling and the measurements of temperature’s tool is needed to estimate the
function ability of the cutting tool too hard milling. Cubic boron nitride (CBN) one of the toughest cutting tool after diamond eligible for machining ferrous materials. Multilayer CBN coatings characterize a novel deposition technique that be able to develop bond on metal substrates. This multilayer CBN structure presented outstanding adhesion in impressive situations level with high residual stress. Compared to monolayer CBN coatings, the multilayer CBN films had lesser elastic moduli, and their serious loads were double as high. The bond of the multilayer CBN structure was meaningfully enhanced since of the induced stress relaxation [5].

Combining with advantages of good coating materials for cutting tools makes this type of great importance for cutting ferrous materials in many branches of industry. CBN cutting tools include certain heat-resistant tools of coated carbide were generally used in the milling of difficult-to-machine things such as aerospace material, die steel or hardened steel [6-7]. The outstanding mechanical and thermal properties such as strength at high temperature, abrasion resistance, and hardness second one to that diamond contains on CBN cutting tools. Thus, the performance of CBN tools in the past few years had been conducted by many types of research [8-9]. The CBN as cutting material’s application is a favorable method and might have a main influence on production. Nevertheless, the presentation of machining, such as progression solidity, tool wear and tool life’s performance, and quality of surface finish is quite meaningfully affected via the difference of the properties’ material in high-performance machining in which the high material removal rate (MMR) is frequently needed especially [10-11]. However, the cutting velocities’ application and attainable tool life of CBN coating are still lower than those of some other tools. Some adjustments and improvements need to do by the increase of coating thickness and implementation of a rotational mechanism during coating. Hard coatings usually have brittle and fewer durable while reinforced coatings are of minor strength. For real-world manufacturing operations, to have coatings with high hardness without losing toughness too much is more required.

2. Methodology
A sample of Carbide and HSS substrate of CBN with standard dimension $\varnothing 10 \times 7.8$ mm was used as the base for composite deposition. Surfaces of the substrate sample were treated by chemical etching and mechanical blasting. Reinforcement ceramic particles of CBN powder will use. CBN powders have exceptional thermal conductivity and provide improved surface integrity machining of hard materials and the measurement of tool temperature is essential in order to calculate the applicability of the tool to hard machining process. CBN one of hardest cutting tool in the grinding of hardened alloy steels, tool steels, nickel, and cobalt-based super alloys. Figure 1 below shows the sample of 7.8mm diameter as a substrate for the EN co-deposition.

![Figure 1](image1.png)

**Figure 1.** Substrate for EN co-deposition (a) solid carbide and (b) high speed steel (HSS)

2.1. Co-Deposition of EN
The HSS and carbide substrate needs sensitizing to stimulate the surface. The equipped via high purity deionized water and AR grade chemicals to all non-proprietary solutions. Subsequently, the pre-treatment procedure structure as showed in Table 1, the Electroless Nickel composite deposition of Ni-CBN was accomplished in three (3) hours to reduce the chemical degradation’s effects. The bright mid-phosphorous ($6 - 9\%$) nickel deposit produced by Electroless Nickel chemicals. Using a Jenway hotplate and temperature maintained at $89^\circ C$ the solution was heated.
Table 1. The procedure of EN Co-deposition and materials

| Type of chemical     | Sopping time |
|----------------------|--------------|
| Circudep 3500AB      | 15 minutes   |
| Uniphase PHP Pre- catalyst | 15 minutes |
| Uniphase PHP Catalyst | 15 minutes |
| Niplast AT78        | 15 minutes   |
| EN SLOTONIP         | 60 minutes   |

2.2. Electroless Coating
A 50g/l of CBN powder with the substrate was added into the bath along. The particles of suspended near the surface were co-deposited onto the surface’s substrate with agitation. The diverse of manufacturer standard pH 4.9 and pH 5.4 pH of the EN solution. By adding 10% ammonium hydroxide, the pH was changed to pH 5.4. The coating period and bath temperature were kept constant at 60 and 89 ± 20°C. The elements were preserved in the EN bath thru some air bubbling agitation or mechanical stirring methods. By using Jenway hotplate with an air bubbling and magnetic stirrer, was performed at 1.2W air pressure was done the mechanical stirring process. The whole coating process sequence is simplified in Figure 2. The Ni-CBN Carbide coated tools showed in Figure 3.

3. Results and Discussion
The characterization of the composite deposition was done by JSM-7800F Field Emission Scanning Electron Field Emission Scanning Electron Microscope (FESEM) coupled with energy dispersive x-ray (EDX). The analysis of process parameters’ influence of the in gaining high particle incorporation was done.

3.1. Morphology – Field Emission Scanning Electron Microscope (FESEM)
Figure 3 below shows the surface morphology from FESEM of Ni-CBN coating taken at different magnifications. Figure 3(i) shows Ni-CBN on HSS substrate whereas Figure 3(ii) on carbide substrate. It shows Figure 3(i) that coating exhibited no micro-cracking, rough structure and diffuse all the surface of the substrate. This is because HSS has high thermal-shock resistances that can ability to make it resistant to sudden and rapid temperature changes [12]. Besides that, HSS is able to withstand wide temperature variations.
Figure 3. Ni-CBN coating morphology on (i) HSS substrate at magnification of (a) 5000X (b) 15000X (c) 50000X and (ii) Carbide substrate at magnification of (a) 5000X (b) 15000X (c) 50000X

Figure 3(ii) shows some micro-crack were present on the external layer of the coating surface for the carbide substrate. This is because Carbide has low thermal resistance to heat. It was due to the high internal stress level to be able to lead to some complications in the usage of the coating. The problems such as loss of deposit adherence crack formation in the coating and the part by the fatigue of the substrate have the premature breakdown [12].

The comparison of surface morphology with scale 150000X between HSS substrate and Carbide substrate is shown in Figure 4(a) and Figure 4(b) by EN co-deposition. The coating contains mostly white areas for ceramic CBN powders, grey areas for metallic Ni matrix, and dark areas for pores. Overall, the uniform distribution of ceramic particles on HSS coating surfaces was shown compared to the carbide substrate. Carbide substrate shows the cracking on the coating surface due to the thermal gradient. Overall, both figures show the rough surface of the coatings. This is because the roughness of electroless nickel boron deposits is dependent on the substrate roughness. This is due to the growth mechanism of the coating that forms columns locally perpendicular to the surface. The coating will be even smoother than the substrate if the substrate is smooth and the columns will be parallel [13].
Figure 4. Comparison Ni-CBN coating surface morphology (15000X) between (a) HSS substrate (b) carbide substrate

Table 2. Composition of as-plated electroless Ni-CBN coatings on HSS substrate

| Element | Weight% |
|---------|---------|
| B       | 20.69   |
| C       | 16.71   |
| N       | 9.16    |
| O       | 15.01   |
| P       | 4.20    |
| Ni      | 34.22   |
| Totals  | 100.00  |

Figure 5 shows the EDX spectrum found for the Ni-CBN deposited on HSS substrate and Carbide substrate shown in Figure 6. The presence of peaks consistent with CBN confirming the co-deposition of elements in Ni-matrix. There are show the presence of major peak elements of nickel (Ni) followed by boron (B), carbon (C), oxygen (O), and phosphorous (P) were existing. This is proved that the mixtures are composed of a combination of ceramic CBN and metallic nickel. Since phosphorous is one of the major elements in the EN hypophosphite-base bath solution has shown by the presence of a phosphorous element in the composite [14].

Table 3. Composition of as-plated electroless Ni-CBN coating on carbide substrate
| Element | Weight % |
|---------|----------|
| B       | 11.65    |
| C       | 21.81    |
| N       | 4.40     |
| O       | 21.34    |
| P       | 7.07     |
| Ni      | 33.73    |
| Totals  | 100.00   |

Figure 6. EDX Spectrum of as-plated area of Ni-CBN coated on carbide substrate

4. Conclusions
The summarized conclusions are as follows:

i. FESEM showed the existence of major peak elements of nickel (Ni), boron (B), oxygen (O), carbon (C) and phosphorous (P) on HSS carbide substrate were present. The both substrates being coated by Ni-CBN was proven.

ii. High internal stress level to be able to lead to some complications in the usage of the coating, such as loss of deposit adherence crack formation in the coating and the part by the fatigue of the substrate have the premature breakdown.

5. Conclusions
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