Investigation and Optimization Key Parameters Effect on Cutting Feasibility of Electroless Ni-CBN on Carbide End Mill Cutting Tools by Taguchi Method

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Abstract. Nowadays, coated cutting tools are extensively used in the cutting manufacturing industry, which gets to the important developments in cutting tool performance and economy thru reducing tool wear of cutting tools, low cutting forces, and better-quality surface roughness of the workpiece. From this research, the effects of feed rate, spindle speed and depth of cut on the surface roughness using electroless Nickel-CBN coated cutting tools (carbide) were measured experimentally. The parameters of machining’s setting were determined by using Taguchi’s L9 (3³) was used in this study. The S/N ratio with analysis of response in optimization and ANOVA results were used to recognize the best significant parameters affecting the surface finish. From this experiment, the outcome shows that the feed rate parameter most affected to the surface roughness. The optimum setting parameter’s levels are spindle speed 3, feed rate 3, and depth of cut 2. So, the optimum machining settings are spindle speed of 3450 rpm, a feed rate of 334 mm/min, and depth of cut 2 mm.

1. Introduction
Electroless Ni 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 [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 [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 [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].

Good coating materials for cutting tools makes this type of cutting ferrous materials becoming important in many branches of industry. CBN cutting tools include certain heat-resistant that is generally apply to the difficult-to-machine materials, for example, aerospace material, die or hardened steel [6-7]. The exceptional mechanical and thermal behaviour, i.e. high temperature strength, abrasion resistance, and hardness comparable to diamond can be found in the CBN cutting tools. Thus, recently it is proven that the CBN tools accomplished high outcome in 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 quiet 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. Experimental

End mill cutting tools (9 units) of Carbide with dimension 6 mm was used as the substrate for composite deposition. Reinforcement ceramic particles of Cubic Boron Nitride (CBN) powder were used in this study. CBN powders offers the excellent thermal of conductivity in addition offer better surface finish in the grinding process of hardened alloy steels, tool steels, nickel, and cobalt-based super alloys. Figure 1 below shows the sample of Ni-CBN carbide coated end mill as a substrate for the electroless nickel co-deposition.

![Figure 1. End Mill Carbide as Substrate for EN Co-Deposition](image)

2.1 Co-Deposition of EN

The 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°C the solution was heated.

| Type of chemical       | Dipping time/Minutes | Heat of Temperature/ °C |
|------------------------|----------------------|-------------------------|
| Circudep 3500AB        | 15                   | 60                      |
| Uniphase PHP Pre-catalyst | 15            | 20                      |
| Uniphase PHP Catalyst  | 15                   | 40                      |
| Niplast AT78           | 15                   | 40                      |
| EN SLOTONIP            | 60                   | 89                      |

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.
2.3 FESEM and EDAX analysis

Figure 4 shows JSM-7800F Field Emission Scanning Electron Microscope (FESEM) equipped with energy dispersive x-ray (EDX) machine to analyse FESEM and EDAX. The microstructure of work material (Ni-CBN) is shown in Figure 5. EDAX analysis was done for carbide specimens. Figure 6 show EDAX results display the existence of Nickel in high percentage and the other alloys in low percentage. B, C, N, O, and other alloys existing in carbide are also realised. The process of electroless Ni-CBN coated on the carbide substrate reveals perfection in the elemental characterization.
3. Setting the Design of experiment (DOE)

The greatest significant step in the design of an experiment depends on the variability of factors’ control and classifying of the Orthogonal Array (OA) before organizing the experimentation created by specific OA.

3.1 Classifying the Orthogonal Array (OA)

The consistent OA L9 (3^3) was used in this research. It contains nine tests with three different types of factors and different types of trial state levels. Table 2 was stated the factors and levels. The depths of cut and feed rate were designated based on preferences specified by the end mill producers. The selected of spindle speeds were three times refer to the suggested change of speeds to the experimentation into the “high cutting speed” type [15, 16]. Table 3 show the nine experiments of coated carbide end mills with the particulars of the mixture in investigational levels for every control factor (A–C).

3.2 Investigational data S/N ratio

The Taguchi optimization method using to running the testing according to the selected of OA. Deckel Maho DMU 50 CNC Milling Machine was used as selected machine. The pocket-milling process was chosen as research by using the recommended experimental setting to study the cutting performances process. A process of machining using a rectangular workpiece of Aluminum Alloy 7075 as Figure 7 was prepared in 40mm x 35mm x 10mm is designated as research. Three different parameters such as feed rate, spindle speeds, and depth of cut were used to machine the work materials. EN-CBN carbide end mill with new cutting tools was used for each number the run for machining experiments. Mitutoyo Surface Roughness Tester SJ-210 as Figure 8 was measured the average surface finish (Ra) in the different locations on the machined surface.
Figure 8. SJ-210 Portable Surface Roughness Tester

Table 2. Control Factors and Experiment Levels

| Factor               | Trial Condition Level |
|----------------------|-----------------------|
|                      | 1         | 2         | 3         |
| A. Spindle Speed (rpm) | 1860     | 2650     | 3450     |
| B. Feed Rate (mm/min)  | 180      | 257      | 334      |
| C. Depth of Cut (mm)   | 1         | 2         | 3         |

4. Results, Discussion and Analysis

4.1. Experiment Data and S/N Ratio

The machining parameters such as feed rate, spindle speed, and depth of cut were designated for directing tests. Table 3 shows the machining parameters, measured surface roughness (Ra) and S/N ratio. The signal to noise (S/N) ratio is determine by the quality condition of smaller-the-best, larger-the-better, or normal-the better. The equation for calculating the S/N ratio for smaller the better features (in decibel) is as follows [17]:

\[
S/N = -10 \log_{10} \left( \text{Sum} \left( \frac{y^2}{n} \right) \right)
\]

where \( y \) is the mean value of surface roughness.

\( (1) \)
Table 3. Investigational Results via L9 OA for Coated End Mills Ni-CBN Carbide

| Experiment No. | Spindle speed (rpm) | Feed Rate (mm/min) | Depth of cut (mm) | Surface roughness Ra (µm) | S/N ratio (d/B) |
|----------------|---------------------|--------------------|-------------------|---------------------------|-----------------|
| 1              | 1860                | 180                | 1                 | 0.365                     | 8.75414         |
| 2              | 1860                | 257                | 2                 | 0.457                     | 6.80168         |
| 3              | 1860                | 334                | 3                 | 0.615                     | 4.2225          |
| 4              | 2650                | 180                | 2                 | 0.365                     | 8.75414         |
| 5              | 2650                | 257                | 3                 | 0.478                     | 6.41144         |
| 6              | 2650                | 334                | 3                 | 0.721                     | 2.84129         |
| 7              | 3450                | 180                | 1                 | 0.453                     | 6.87804         |
| 8              | 3450                | 257                | 3                 | 0.542                     | 5.32001         |
| 9              | 3450                | 334                | 2                 | 0.887                     | 1.04153         |

4.2 Regression Equation
The feed rate, spindle speed, and depth of cut were set with parameters to produce equations for surface roughness. Equation (2), stated the linear equations generated with the main effects of the control factors for surface roughness.

Regression Equation

\[ Ra = -0.256 + 0.000093 \text{ Spindle Speed} + 0.002251 \text{ Feed rate} - 0.0137 \text{ Depth of Cut} \]  

(2)

Figure 9. Normal Probability Plot for Ra
4.3 Analysis of Variance

The main purpose of ANOVA is to analyse the extent to which various parameters affect the response variables. In the ANOVA analysis, the 95% was chosen as significance level, and the parameter was measured to be operative on the output when the $P$-value was less than 0.05 [19]. In this study, ANOVA analysis of trial data was designed to analyse the relative significance of the factors such as cutting speed ($A$), feed rate ($B$), and depth of cut ($C$) on the response variable (surface roughness $Ra$). The model was developed for a 95% Confidence level. The model $P$-value designates that the model is significant with negligible influence of noise. A first-order model has been developed using Minitab software according to the experimental results of the Surface roughness.

Based on ANOVA Table 4, the analysis of feed rate, spindle speed, and depth of cut was evaluated and with chosen $\alpha$-level of 0.05. The results show the $p$-value of the feed rate factor is lower than the other factors. This show the effect of feed rate is significant. The $p$-value factors is not significant as long as the $P$-value $>0.05$ [18].

| Machining parameter | Degrees of freedom | Sum of squares | Mean square | F-value | $P$-value |
|---------------------|--------------------|----------------|-------------|---------|----------|
| Spindle speed       | 2                  | 0.035031       | 0.017515    | 4.85    | 0.171    |
| Feed rate           | 2                  | 0.191617       | 0.095808    | 26.55   | 0.036    |
| Depth of Cut        | 2                  | 0.004428       | 0.002214    | 0.61    | 0.620    |
| Residual Error      | 2                  | 0.007216       | 0.003608    |         |          |
| Total               | 8                  | 0.238292       |             |         |          |

4.4 Determination of Optimum Factor Level Combination

From the response Table 5, the feed rate is the significant factor affecting surface finish followed by spindle speed and depth of cut. The feed rate is the most important machining parameter that affects the surface roughness because it delivers main the most significant influence on the surface roughness [20]. Table 5 shows the Taguchi response shown in which is to find out the optimal factors that affect to the surface roughness. The optimal machining settings were determined as a 3450 RPM for spindle speed, 334 mm/min for feed rate of, and 2 mm for depth of cut. Optimum parameter’s level A3B3C2 will use for conducting the validation experiment using the S/N ratio. Surface roughness was the greatest effect by spindle speed and feed rate as shown in Figures 10 and 11. The slope between the horizontal and feed rate line is bigger than spindle speed. It means that the feed rate changes affected significantly on surface roughness [21]. The value setting of spindle speed of 3450 RPM, a feed rate of 334 mm/min, and depth of cut 2 mm were determined as the optimum machining condition.

| SNO | Level | Spindle speed | Feed Rate | Depth of cut |
|-----|-------|---------------|-----------|--------------|
| 1   | 1     | 6.593         | 8.129     | 5.638        |
| 2   | 2     | 6.002         | 6.178     | 5.532        |
| 3   | 3     | 4.413         | 2.702     | 5.837        |
| 4   | Delta | 2.180         | 5.427     | 0.305        |
Figure 10. Graph of Main Effects Plot for SN Ratios

Figure 11. Graph of Main Effects Plot for Means

Figure 12 shows the interaction plot for surface roughness for the machining procedure. An interaction occurs. The more nonparallel the lines are, the greater the strength of the interaction. It shows the feed rate parameter of machining affects the surface roughness more than other factors (spindle speed and depth of cut) for the milling cutting procedure of Aluminum Alloy 7075 using Ni-CBN Carbide coated end mill.
5. Conclusions
From the study, effects for surface roughness by the optimization of machining parameters using high-speed machining was done for Aluminum alloy 7075 material using the OA L9 (3^3). A total of nine experiments were conducted using three different variable parameters and trial state levels. The S/N ratio and ANOVA response investigation were used to analyse result in dual different methods. However, the results were delivered similar from both methods. The summarised results are as follows:

1. Show the existence of Nickel in major percentage (33.73%) and the existence of other alloys in minor percentage. B, C, N, O, and other alloys existing in carbide is also seen. The elemental description reveals perfection in the development of electroless Ni-CBN coated on the carbide substrate.
2. Regression Equation for Ra = -0.256 + 0.000093 Spindle Speed + 0.002251 Feed rate - 0.0137 Depth of Cut.
3. From the table of ANOVA, the results show factor of feed rate is significant parameter designates the p-value of the feed rate factor is lower than other factors of the P-value< 0.05. The P-value for the feed rate factor is 0.036.
4. The parameters influencing low surface finish are feed rate, cutting speed, and depth of cut, correspondingly from the response table for the signal to noise ratio (smaller is better).
5. Optimum parameter’s level A3B3C2 will use for conducting the validation experiment using the S/N ratio analysis.
6. The optimal machining settings are determined as a spindle speed of 3450 RPM, a feed rate of 334 mm/min, and depth of cut 2 mm.

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**Acknowledgments**

The authors gratefully acknowledge to the University College TATI due to the research is fully supported by Short Term Grant (STG) UC TATI 9001-1808 under Advanced Manufacturing Cluster.