Introduction

1. The motivation of the study

The grinding increasingly account for a large proportion of the part machining process due to the grinding not only provides a high accuracy for machined parts but also plays an important role on the quality of products. In the grinding process, the grinding wheel plays as a significant factor on the quality and the cost for the grinding process. The electroplated metal-bonded CBN (EMcBN) grinding wheel has many advantages in the grinding of materials with high hardness, in shaped-grinding process, or manufacturing grinding tool used for wheel correction. In addition, there are many advantages of the kind of the grinding wheel such as faster manufacturing time, using less abrasive resulting of a low cost.

Currently in Vietnam, CBN grinding wheels are popularly used at foreign direct investment companies in the machining process. However, the CBN grinding wheel mostly is imported, while there is not any research on technology and manufacturing produce for these wheel at Vietnam yet. So the dissertation "Research on fabrication and assessment cutting ability of electroplated metal-bonded CBN grinding wheel" in order to set the original base for the research on manufacture of EMcBN grinding wheel in Vietnam.

2. Research objective of thesis

- Research on fabricating EMcBN grinding wheel grinding wheel.
- Assess the durability of the bonding and cutting ability of EMcBN grinding wheel.

3. Research subjects

- The EMcBN grinding wheel on C45 steel substrate and cutting ability of EMcBN grinding wheel.

4. Research Methodology

- Sample selection study: Conduct analysis of samples of EMScBN grinding wheel from Japanese and Chinese manufacturers to have the theoretical and practical basis to serve for the research process.
- Combination of theory and experimental study: while theoretical study to determine the relationship between technology parameters of the manufacturing process, experimental study is used in the fabrication process and experimental cutting of the grinding wheels to evaluate the characteristics of the grinding wheels.

5. Limit the scope of the study

- Research on technology for EMScBN grinding wheels with cylindrical shape, diameter Φ10÷Φ15, the length of 10÷15mm, CBN particle size #140/170 corresponds to the size of the abrasive from 90÷106μm.
- Assessment of the cutting properties of the grinding wheel is conducted with the surface grinding process. The grinding ratio and surface roughness of machined surface are two parameters to evaluate the cutting ability of the grinding wheel.

6. The scientific and practical contribution of the study

Scientific contribution:

The results of this study have scientific contributions: The study of apply electroplating technology to fabricate metal-bonded single-layer CBN grinding wheel; determine the impact of the technology parameters (current density, plating time, rotation speed of catot, temperature of the solution) of electroplating process (EP) to the distribution of the abrasive on grinding wheel surface in the fabrication; assess the cutting ability of the grinding wheel through the G-ratio and surface roughness of machined surface.

The study initially creates the scientific basis for manufacturing technology for the fabrication of EMcBN grinding wheel in Vietnam.

Practical contribution:

The research results of the thesis are the starting step for the fabrication of EScBN grinding wheel in laboratory. Then, it can be applied to actual production in Vietnam and be references for teaching and scientific research in the future.

7. Results of the research study

- Proposal a fabrication method and a set of technology parameters to fabricate EMcBN-grinding wheel.
- Establishment the formula for distribution coefficient (K_{PBQU} and K_{PBT}) and the equation for determining the approximate plating thickness
- The method of assessment of cutting ability of EMScBN grinding wheel

Research content and layout of the thesis

The content of the thesis is presented in four chapters: Chapter 1: Overview of research problems; Chapter 2: Materials and Research Methodology; Chapter 3: Study on design and manufacturing of laboratory equipment for fabrication of MBcBN grinding wheel; Chapter 4: Research, manufacture and evaluate the cutting ability of MBcBN grinding wheel.

CHAPTER 1: OVERVIEW OF RESEARCH ISSUES

1.1. The grinding process, CBN grinding wheel and CBN single-layer grinding wheel

1.1.1. Grinding process

The grinding increasingly account for a large proportion of the part machining process due to the grinding not only provides a high accuracy for machined parts but also plays an important role on the quality of products.

1.1.2. Grinding wheel - composition and structure

Grinding wheel plays an important role on the quality and cost of grinding process. The structure of the grinding wheel consists of 3-phase: grinding abrasive, bond and pores.

1.1.3. CBN grinding wheels

CBN grinding wheel is increasingly used in the field of the grinding. The hardness of CBN abrasive is approximately 4500 kG/mm^2 , being 2nd hardest material after diamond, with high heat resistance, good thermal conductivity, high corrosion-resistant in the grinding process of alloys containing carbon. CBN grinding wheel is manufacturing in the form of single-layer or multilayer.

1.1.4. The fabrication method CBN grinding wheel

1.1.4.1. CBN grinding wheel multilayer (grinding wheel general)

CBN grinding wheel multilayer is mainly manufactured by sintering method with vitrified or metal bonds . Besides that, it can be manufactured by means of vulcanization (at 150 ÷ 200°C) with a plastic bond.

1.1.4.2. CBN grinding wheel single-layer

Single-layer grinding wheel is manufactued by three methods: Brazed method, chemical plating method (eletroless plating method) and EP.

a) Brazed method : is the method of attaching the abrasive on the metal body by a chemical reaction between the abrasive, bond and wheel body. The coating thickness is of about 20÷30% of the average size of the abrasive . This grinding wheel has large chip evacuation and reduces the grinding forces. However, the brazed process performed at high temperatures up to 1000 °C, thereby reducing the reliability of the particles, causing deformation wheel body and around the abrasive position under tensile stress in the cooling process. Equipment in the process used is very expensive and high demand of wheel body.

b) Chemical plating method: use the chemical plating method of nickel-phosphorus with heat treatment allowing increased reliability of nickel plating. The disadvantage of this method is low productivity, expensive equipment; high temperature, cracking due to the brittleness of the bonding layer.

c) Electroplating method: is the common method to fabricate single-layer grinding wheels which is carried out at low temperatures (below 100 °C). The advantage of this grinding wheel is abrasive particles uniformly distributed on the surface of grinding wheel, topography of grinding wheel depends on the profile of the metal core. CBN grinding wheel is by EP has the advantages of high yield and simple device, easy to fabricate thin grinding wheel, grinding wheels for processing shaped surfaces without dressing. At the same time, wheel body can reuse after abrasive particles worn thereby enhancing economic efficiency when using this grinding wheels.

1.2. Fabrication method of grinding wheel by EP

1.2.1 The concept of EP

1.2.1.1. The formation of metal-plated coating on the cathode

1.2.1.2. Composite coating and coating techniques

Composite coating is generated by co-deposition of solid particles with metal plating from a slurry solution. Slurry solution is created by mixing a determined amount of solid particles into the plating solution.

1.2.1.4. Effects of parameters to the process of electroplating.

Parameters affecting the electroplating process include current density; pH; temperature; composition of solution; speed agitator; surface preparation; time.

1.2.2 Application of EP to form bonds of grinding wheel

The CBN grinding wheel manufactured by EP technology uses the composite plating to form coating of CBN particles. However, the CBN particles are not completely buried but only partly of CBN abrasives buried as cutting blade in cutting process.

1.2.2.1. Bond materials

The CBN grinding wheels uses a single nickel layer as the. Fabrication process single-layer CBN grinding wheel by EP with nickel bond is the co-deposition of Ni-based CBN on the metal substrate.

1.2.2.2. Plating solutions

Two types of suitable solutions for nickel and nickel-composite plated layer in the manufacturing of grinding wheel are Watts solution and sulphamate solution. The disadvantages of sunfamate solution are delamination of plating layer off the substrate, toxicity and high cost. Therefore, Watts solution is highly recommended to fabricate nickel plating layer and nickel composite layer plated layer.

1.3. The facts of this research Vietnam and abroad

1.3.1. Research study abroad

In 1991, AK Chattopadhyay and colleagues studied on innovation of CBN single layer grinding wheel fabricated by EP in the grinding. By observing CBN grinding wheel surface, there is the emergence of the bond in the space between the abrasive particles that reduces the cutting ability of the grinding wheel.

There are a number of studies on micro grinding wheel by EP with diameter ϕ = 100÷ 500 µm, using diamond particles of small size 2÷ 4 µm, 7.5÷ 12 µm and 8 ÷ 16 µm.

In 2014, Yu Zhang and colleagues, research and manufacture of diamond grinding wheel by EP using diamond particles coated with a nickel component. The nickel-coated diamond particles are separated partially nickel coating, then coated on JIS S45C steel. The abrasive sized 30÷40 µm. The sulfamate solution is used for plating composite, but the plating solution before and after the composite plating solution is Watts solution.

1.3.2. Domestic research

In Vietnam, there is not any research available about the CBN grinding wheel fabricated by Metal-based EP. However, there is few relating research on the use of composite coating technology for the fabrication of functional coating as follows:

There are a few number of researches on plating technology of nickel composite using a Watts solution with modified nanoscale particles Al_2O_3, TiO_2, CeO_2 or CNTs to create a functional abrasion, catalysts, corrosion surface or super hydrophobic on the metal surface.

1.4. 5. Limit the scope of this research:

Within the scope of the thesis, research content will be implemented are: research on fabrication EMcBN grinding wheel with Watts solution with following specifications:

+ Grinding cylinder diameter from 10 ÷ 15 mm, length 10 ÷15 mm; CBN grinding particle size #140/170 corresponds to the size of the abrasive 90÷106μm; electroplating nickel bond.

+ Assessing's cutting ability of grinding wheel in the grinding through two parameters: G-ratio and the surface roughness of the workpiece.

CONCLUSION CHAPTER 1

From the results of the overview research, the following conclusions are drawn:

There are three methods to fabricate single layer grinding wheel currently used: brazed, chemical plating and electroplating. Electroplating method has advantages of high yield, does not require complex device, grinding wheel with good quality and suitable for the production conditions in Vietnam.

The CBN grinding wheel can be made by electroplating method to create composite Ni-CBN abrasive coating on the surface of the metal core. Characteristics of the plating process composite Ni-CBN is the CBN particle size in the range of 90 ÷ 106 μm. The abrasive must be partly linked in the coating layer and partially protruding to the surface to perform the grinding function. Watts solution is used to perform plating process of a nickel layer and a composite Ni-CBN.

The objective of this research is fabrication of EMcBN grinding wheel in the laboratory with the specifications: grinding cylinder diameter from 10 ÷ 15 mm, length 10 ÷ 15 mm, particle size to produce CBN grinding wheel #140/170 corresponds to the size of the abrasive from 90 ÷ 106 μm.

CHAPTER 2 MATERIALS AND METHODS

2.1. Materials, chemicals and equipment

2.1.1. Sample of CBN grinding wheel and material:

Sample CBN grinding wheel: EMcBN grinding wheel manufactured by Okazaki in Japan and China's grinding wheels.

Abrasive materials: 2 types of abrasive used in this study.

+ Type 1 abrasive: SiC abrasive, particle size #140/170 (90 ÷106 μm), originally used to assess the quality of the fabrication equipments. Specific weight: 3.21g/cm^3 form Hai Duong grinding wheel Corporation.

+ Type 2 abrasive: CBN grain used to produce composite coating Ni-CBN is CBN type 10A+. The abrasive has yellow color, particle size #140/170 (90 ÷ 106 μm), specific weight of 3.48 g/cm^3 provided by Ultra-Hard Changsha 3 Better Materials Co., Ltd, China.

Anode electrode materials: Nickel electrode plates in sheet form.

Steel wheel material (cathode): the C45 machined cylinder with diameter of 10 ÷15 mm and plating length 10÷15 mm. The steel wheel is machined smooth, polished, washed, degreasing, rust remover and dried.

Material of grinding workpiece: Workpiece material is steel grade SDK 11 in size of 24x45x10 mm, heat treatment to achieve hardness of 60 ÷ 63 HRC

2.1.2. Chemicals and equipment

Chemistry: The chemicals for mixing of nickel plating solution include: $NiSO_4.7H_2O$:300 g/L; $NiCl_2.6H_2O$: 60 g/L; H_3BO_3: 30 g/L; Lauryl sulphate sodium: 0.1-0.15 g/L.

Chemicals for making composite plating solution Ni-CBN include: $NiSO_4.7H_2O$: 300 g/L; $NiCl_2.6H_2O$: 60g/L; H_3BO_3: 30 g/L; Lauryl sulphate sodium: 0.1-0.15 g/L, 160 g/L grain CBN grain size #140/170.

Equipment and tools for electroplating process: *sample cup, experimental tanks, plating power supply, heating magnetic stirrer.*

Device to evaluate coating quality: CNU500X optical microscopes; Scanning electron microscope (SEM) JEOL JSM-6510LV; 4 digits electronic analytical weighter AB204-5: Machine roughness measuring probe contact type SJ 400; Electronic micrometer Mitutoyo 293-240 Series.

2.2. Methods of determining the properties of composite coating Ni-cBN

2.2.1. Determine the chemical composition

Methods of energy-dispersive X-ray spectroscopy (EDX) is used to determine the chemical composition of the coating.

2.2.2. Determine the abrasive density surface

- *Observations on the optical microscope:* to observe the level of abrasive distribution on the sample surface.

- *Observation by SEM:* Allowing observations in higher magnification and determine the density distribution of the abrasive particles by counting them at any two locations on the surface of the samples. The average value is used to determine the coefficient K_{PBT}.

- *Determine the distribution coefficient K_{PBQU}:*

$$K_{PBQU} = \frac{m_{hatCBN}}{m_{1hatCBN} \times S_{ma}} \quad \text{(particle/mm}^2\text{)} \qquad (2\text{-}8)$$

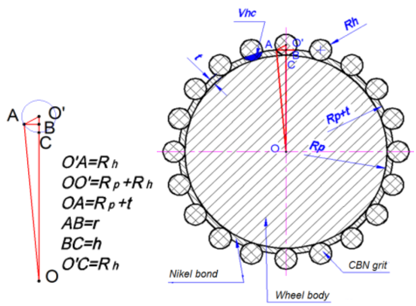


Figure 2.8. Diagrams for calculation of thickness of plating layer

which m_{hatCBN}: CBN particle mass is determined by the difference in the volume and mass of plating components and nickel-plated coating.

2.2.3. Determination of plating thickness

Two methods were used to determine the thickness of plating:

- *By calculation: Plating thickness is determined from the equation 2-19:*

$$m.t^3 + n.t^2 + pt + q = 0 \qquad (2\text{-}19)$$

$$\text{Where} \begin{cases} m = K_{pb}.\pi \\ n = -3.K_{pb}.R_h.\pi. \\ p = 3 \\ q = -\frac{3.m_{Ni}}{\rho_{Ni}.S_{ma}} \end{cases} \qquad (2\text{-}20)$$

- *By measurement:* The cross-sections of grinding wheel samples were prepared for coating thickness measurement and SEM photography.

2.2.4. Assessment of the adhesion of abrasive on the metal plating layer

The setup for the grinding experiments is shown in Figure 2.11. The X, Y, Z motions are controlled by CNC with the smallest movement of 1µm. The grinding conditions: grinding speed: 12.56 m/sec; grinding depth: 0.005 and 0.010 mm; feed rate: 300 mm/min; surface grinding; no lubrication (dry grinding).

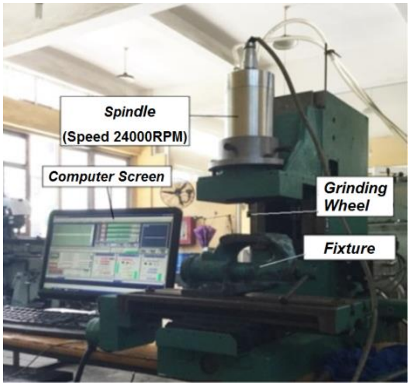


Figure 2.9. Experimental grind machine

The observations of adhesion layer and grinding experiments were both used to evaluate cutting properties of the grinding wheel, which is also used as a tool for strength evaluation of adhesion layer. The cutting ability of the grinding wheel is evaluated through two parameters, grinding ratio and surface roughness of the grinding workpiece.

2.3. Experimental study on the influence of technological parameters to the distribution of CBN particles in composite coating Ni-cBN

2.3.1. Selection of the studied parameters:

Many factors affect the distribution of the CBN abrasive on the grinding wheel, however, this study focuses on 4 factors: temperature of plating solution (50-60 °C), current density (1÷ 8 A/dm^2), composite plating time (5 ÷ 15 minutes), the rotation speed of steel body wheel: 0.7 ÷ 3 rev/minute.

2.3.2. Method of experimental study

To study the influence of parameters to the distribution of abrasive on the grinding wheel, the changing in each parameter was implemented, while the other parameters were fixed. Based on the experimental results the set of three reasonable paramters was pick up to study their effects simultaneously to find the distribution function of the abrasive particles. Using the method of experimental study on the Response Surface Design (RSD) with Central Composite Design (CCD).

CONCLUSION OF CHAPTER 2

From the above analysis, the following conclusions are drawn:

The CBN grinding wheels were manufactured with CBN abrasives type 10A+ (particles size of 90 ÷ 106 µm), the bonding material of nickel and the Watts solution with main composition of nickel salt.

The formula for distribution coefficient (K_{PBQU} and K_{PBT}) and the equation for determining the approximate plating thickness was established.

The chemical composition of the sample is determined using the EDX method. The thickness and distribution of particles on the surface of the fabricated grinding wheel were calculated and observed on optical microscope, scanning electron microscope and cross section of the grinding.

The experimental methodology of CCD is used in this research to study the effects of 3 technology parameters and the distribution of the abrasives on the grinding wheel surface.

The strength evaluation of adhesion layer is obtained by scanning electron microscope and grinding test.

CHAPTER 3 RESEARCH ON MANUFACTURING OF LABORATORY FABRICATION EQUIPMENTs FOR SINGLE LAYER CBN GRINDING WHEELS BY EP

3.1. Requirements and technical parameters of laboratory equipment

3.1.1. Requirements

Laboratory equipment for the plating can adjust operation parameters such as plating solution's temperature; current density; solution stirring speed; rotational speed of the body steel wheel (cathode).

3.1.2. Technical parameter

The plating process was performed with small wheel body, so the selection of equipment which is available on the market is preferred. The laboratory equipment includes: Power Supply: I_{max} = 25 A with the adjustment of 0.01 A, U = 0÷12 V. Heating for plating solution has the ability to control and stabilize the plating solution's temperature from room temperature to 100 °C degrees. The stirring speed for the plating solution was controlled 0÷1500 rev/min. Rotating equipment for plated wheel can run at speed from of 0.7÷ 5 rev/min.

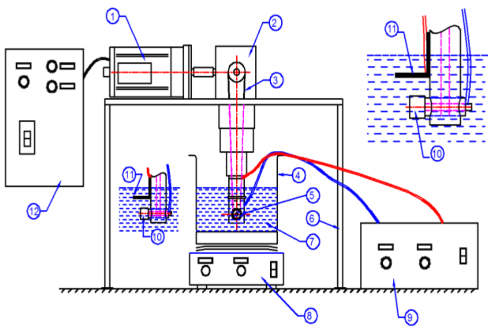


Figure 3.4. Model EP laboratory equipment

3.2. Design and manufacturing of laboratory equipment

The research process and complete the fabrication of laboratory equipment is done through the plating experiments. The configuration of experimental model is presented in Figure 3.4.

3.3. Quality evaluation of laboratory equipment

Quality of fabrication equipment was assessed through the quality observation of plating wheel with the changes of the operating parameters such as: plating time, plating solution’s temperature, current, the rotation speed of the cathode. The results show that the model configuration with a rotating wheel body (cathode) horizontally is appropriate. With this experimental model, not only the CBN grinding wheel can be created with abrasive layer around the wheel body, but also the effect of operation parameters to the formation of the composite coating can be studied.

CONCLUSION CHAPTER 3

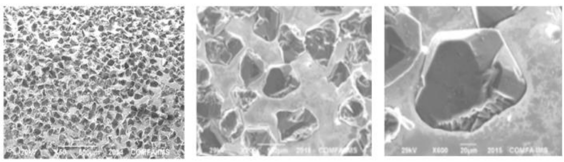
The laboratory equipment has designed and built successfully to serve the research in next chapter. The plating equipment meet the wide range of specifications to serve for fabrication of CBN grinding wheel. With the devices, the study on the effect of technology parameters to the electroplating process to the formation of CBN layer on the surface grinding wheel can be implemented.

CHAPTER 4: STUDY OF FABRICATION AND ASSESSMENT OF CUTTING PROPERTIES OF CBN GRINDING WHEEL

4.1 Surface structure of the EMcBN grinding wheel

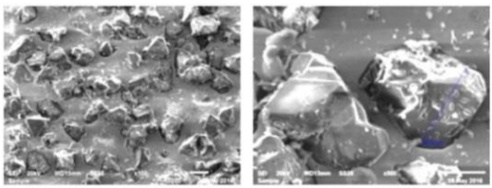
4.1.1. Features of CBN grinding wheel

The study on surface structure of the samples of EMScBN grinding wheel which are available on the market of Japan and China was first carried out. From the study of these samples, the following features can be seen:



a) ×50 c) ×200 d) ×600

Figure 4.1. SEM images of the surface of cBN grinding wheel from Japan



a) ×100 b) ×500

Figure 4.2. SEM images of the surface of cBN grinding wheel from China

SEM surface image of the CBN grinding wheel from Japan (Figure 4.1) shows CBN abrasive particles distributed relatively evenly on the wheel surface. However, the Chinese grinding wheel shows CBN abrasive with less uniform distribution than Japanese ones (Figure 4.2)

CBN grain sizes are in the range of 94 ÷ 107 µm. The abrasive not buried completely, but only partly buried into the plating layer creating adhesion. A part of the abrasive protrudes from the surface of the adhesion layer to ensure a space for chip evacuation in the grinding process.

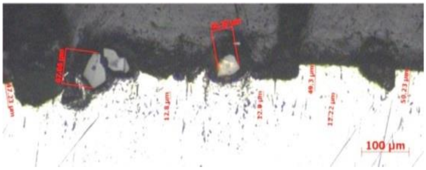


Figure 4.4. Coating thickness

The SEM image of a cross section of CBN grinding wheel shows that the abrasive particles partially buried (Figure 4.4). Some areas, abrasive particles were peeled out leaving a cavity at the position of the abrasive.

Table 4.1. Coating thickness

	1st measure (µm)	2nd measure (µm)	3rd measure (µm)	***Average value*** (µm)
1st Layer	12,8	12,9	12,22	12,64
2nd Layer	47,23	49,3	50,23	48,92

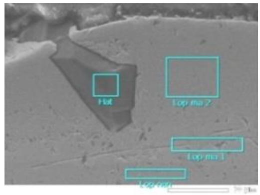


Figure 4. 5. The region EDX analysis of the coating associated grindstone

Table 4.2. Analysis results in vol% of elements in various regions of the grinding wheel

Area	B	C	N	O	Si	P	Fe	Ni	Pb	Total
2nd Layer		8.27			0.4	7.91		83.58		100
1st Layer		7.43		0.62	2.79	0.18	1.11	87.86		100
Substrate		4.01			0.71		94.91		0.37	100
Abrasive	55.69		44.31							100

The plating to mount CBN particle on the steel body includes two layers:

+ 1st layer: background plating is the intermediary between the composite coating and the metal substrate (wheel body). This layer thickness is about 12 µm and is composed mainly of nickel.

+ 2nd layer: composite plating to attach CBN particles to. This layer has also the main component of nickel, a thickness of about 49 µm (about 50% of abrasive particle size).

4.1.2. Requirements for electroplated grinding wheels

General requirements:

Grinding wheel must has high accuracy in profile and dimension: wheel runout are maintained to within 0,01mm, profile tolerances are maintained to within ± 0,025mm. Therefore, the requirements for the surface of the wheel body and surface coating is determined as follows:

- Metal wheel core must be fabricated with high accuracy: wheel runout are maintained to within 0,005mm, profile tolerances are maintained to within ± 0,01mm.

- Coated CBN abrasive particles have the same size and evenly distribution on the surface of the metal core to ensure the uniform distribution of contour. The abrasives' protrudes from the surface of the adhesion layer to must be sufficient to ensure chip evacuation space during cutting. The adhesion bond of the grinding particles must be sufficient to anchor the abrasive during cutting, so the part of abrasive particle penetrate in the adhesion layer must be large enough.
- *Adhesion modeling of abrasive with the plating:* Through the literature and a number of related documents, electroplated CBN grinding wheel surface currently used in Vietnam can be described as shown Figure 4.6. In this modeling, the value of δ should be greater 50% of the medium size of the abrasive. If δ is too big, abrasives' protrudes from the surface is small which reduces chip evacuation and the heat dispersion during grinding leading to increases of grinding forces and temperature. Therefore, CBN abrasive can be easily peeled off from the binder.

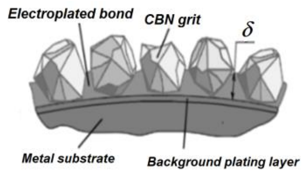


Figure 4.6. Modeling of electroplated grinding wheel surface

The distribution of the abrasive particles on the grinding wheel surface: Depending on user requirements and the working conditions of the grinding wheel, the distribution of abrasive particles can be thick and sparse. In the plating process, to ensure uniform distribution on the region is essential.

4.1.3. Fabricating process of grinding wheel surface

The process of attachment of CBN grinding particles to the surface of metal wheel body is made of the following steps:

- Step 1: Polishing the metal wheel body surface with clean brushes and sand paper;
- Step 2: Cleaning the surface with a preliminary solution for degreasing;
- Step 3: Washing with water;
- Step 4: Cleaning with a solution of 15% hydrochloric acid for pickling and surface activation;
- Step 5: Washing with water;
- Step 6: Plating nickel background layer;
- Step 7: Plating composite Ni-CBN layer to create adhesion CBN to the body surface;
- Step 8: Plating nickel layer to bury particles on the surface.

4.1.4. Quality assessment indicators of composite coating Ni-CBN

a) The distribution of abrasive particles and coating thickness

Distribution coefficient of abrasive K_{PBT} is determined through counting of particle on the surface with SEM images which were taken at two random positions then the average value and coefficient K_{PBQU} were determined by the equation 2-8.

The coating thickness is calculated by equations 2-19 and through SEM image of cross-sections of grinding wheel with taking into account the presence of abrasive particles in the coating

b) Cutting ability of plating composite Ni-CBN

Degree of bonding of the abrasive surface metal wheel core is determined by SEM image of cross sections of the grinding wheel, the burial degree of particles and the bonding to metal wheel body. Bonding strength of the abrasive layer on the metal wheel body is assessed through grinding process by two indicators: grinding ratio and roughness surface of the workpiece.

4.2. Influence of some technological parameters to the distribution of abrasive when fabricating EMcBN grinding wheel

4.2.1. The influence of the plating current density to the distribution of abrasive

Table 4.3 presents the results of experiments and calculations related coefficient distribution of abrasive K_{PBQU} and K_{PBT} and thickness of the abrasive buried in plating with plating current i = 1; 3; 6; 8 A/dm^2 corresponding samples M16, M3, M4, M6.

Table 4.3. The influence of the current density to coating thickness and coefficients K_{PBQU} and K_{PBT} ($T = 55\ ^{\circ}C$, $t_m = 5$ minutes, $n_{ct} = 0.7$ rev/ min)

No	Layer	Current density	Calculated nickel–plated thickness not account abrasive grits		K_{PBQU}	K_{PBT}	$\Delta K_{PB} = K_{PBT} - K_{PBQU}$	Calculated nickel–plated thickness account abrasive grits	
			Individual layer	Embedded thickness				account K_{PBQU}	account K_{PBT}
		(A/dm^2)	(µm)		(particles/mm^2)			(µm)	(µm)
M16	L1	3	13,84		53,48	64,03	10,54	20,61	21,52
	L2	1	0,92	17,53					
	L3	3	16,61						
M3	L1	3	13,84		66,20	76,26	10,07	29,38	31,58
	L2	3	2,77	22,15					
	L3	3	19,38						
M4	L1	3	13,84		69,40	83,20	13,80	29,99	33,59
	L2	6	5,54	22,15					
	L3	3	16,61						
M6	L1	3	13,84		76,93	91,35	14,43	35,76	42,73
	L2	8	7,38	23,99					
	L3	3	16,61						
Layer 1 (L1): Ni plating; Layer 2 (L2): Ni–CBN composite plating; Layer 3 (L3): Ni plating									

Figure 4.11 presents SEM images with different magnifications of the samples. As shown in these figure, the surface structure of CBN grinding wheel fabrication, the CBN abrasive distributed relatively evenly over the sample surface.

However, in samples M16 (i = 1A/dm^2), some areas of the sample surface shows uneven distribution of CBN particle as shown in Figure 4.11a. This can be explained by the small current density in the plating process, nickel precipitated on the surface wheel body is not enough to hold the abrasive on the surface leading to abrasive particles were peeled off with workpiece rotation. Figure 4.13 represents relation of K_{PBQU}, K_{PBT} to the plating current. From the experimental results, following notices can be drawn:

- The current density has significant effect on the CBN particles' distribution on metal wheel body. Level of plated abrasive increases with increasing current density. It is apparent in Figure 4.11.

- In the same experimental conditions: When the current density increases, the amount of CBN abrasive on the surface of the wheel body increases. The current density increased from 1; 3; 6; 8 A/dm^2, the K_{PBQU} increased from 53.48; 66.20; 69.40; 76.93; while values of K_{PBT} increased from 64.03; 76.260; 83.20; 91.35. The difference between K_{PBQU} and K_{PBT} from 10.07 to 14.43, but the relationship between two and K_{PBT} and K_{PBQU} coefficient to the current were similar trend. The reason for the difference between the two coefficients comes from the difference of abrasive particles (spherical and block shape). Due to, the trend of the graph of the 2 coefficient K_{PBT} and K_{PBQU} are similar, so both 2 coefficients can be used to represent for the density of the abrasive particle on the grinding wheel surface

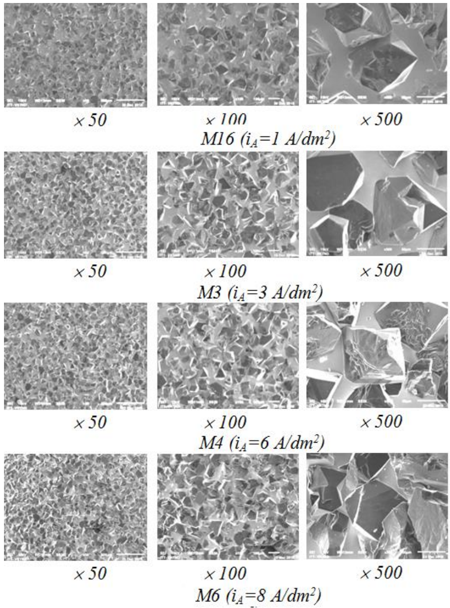


Figure 4.11. SEM images samples M16, M3, M4, M6

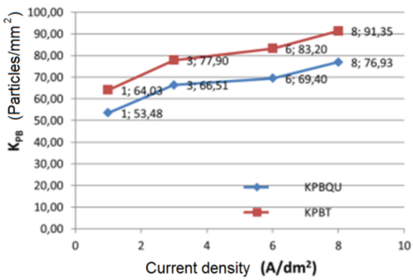


Figure 4.13. K_{PB} and current

4.2.2. The influence of the rotation speed of metal wheel body (cathode)

Table 4.4 presents the experimental results and calculations related coefficient distribution of the abrasive particles and burial thickness of the abrasive particles respect to the rotation speed of wheel body n_{ct} = 0.7; 1.3; 2; and 3 rev/minute (corresponding with sample M3, M9, M11 and M12).

The distribution of the abrasive on the sample surface was observed with the SEM images. Figure 4.15 show the particles distributed relatively evenly on the sample surface. igure 4.17 shows the relationship of K_{PBT} and K_{PBQU} with the rotational speed of plating wheel. From the results of Table 4.4 and Figure 4.17, the conclusion can be seen:

Table 4.4. Effect of rotational speed of wheel body to coating thickness and coefficients K_{PBQU} and K_{PBT} (T = 55 °C, t_m = 5 minutes, I = 3 A/dm^2)

No	Layer	Rotational velocity of the plating wheel	Calculated nickel–plated thickness not account abrasive grits		K_{PBQU}	K_{PBT}	$\Delta K_{PB} = K_{PBT} - K_{PBQU}$	Calculated nickel–plated thickness account abrasive grits	
			Individual layer	Embedded thickness				account K_{PBQU}	account K_{PBT}
		(rev/ min)	(µm)		(particles/mm^2)			(µm)	
M3	L1	0,7	13,84		66,20	76,26	10,07	29,38	31,58
	L2	0,7	2,77	22,15					
	L3	0,7	19,38						
M9	L1	1,3	13,84		60,69	69,74	9,05	24,08	25,14
	L2	1,3	2,77	19,38					
	L3	1,3	16,61						
M11	L1	2,0	13,84		57,49	66,88	9,40	23,64	24,75
	L2	2,0	2,77	19,38					
	L3	2,0	16,61						
M12	L1	3,0	13,84		8,06	11,01	2,95	19,81	19,98
	L2	3,0	2,77	19,38					
	L3	3,0	16,61						

The rotational speed significantly affects the particle distribution of CBN on the surface of the wheel body. The more abrasive on wheel body was observed since reducing the rotational velocity of the plating wheel. The speed with n = 0.7 rev/min (sample M3) has no significant difference to the speed with n = 1.3 rev/min (sample M9) in amount of abrasive particles on the wheel surface. The M11 sample (n = 2 rev/min) have particles distribution less uniform than those in M3 and M9 samples. However, the observation on the surface of M11 (n = 3 rev/min) and M3 sample (n = 0.7 rev/min) shows significantly difference in density distribution of abrasive particles.

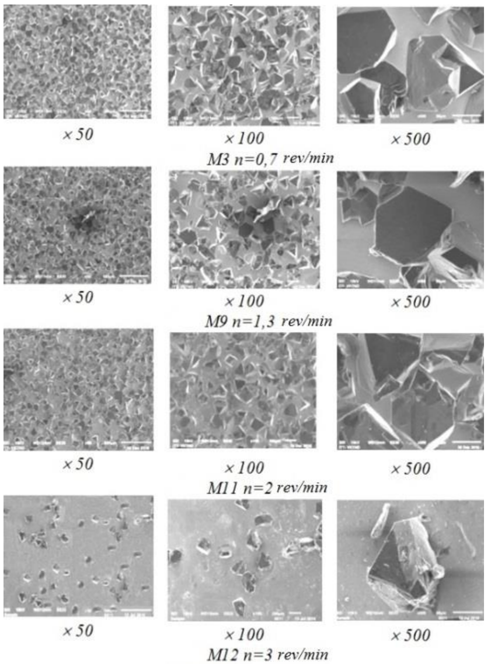


Figure 4.15. SEM images samples M3, M9, M11 and M12

- With the same

experimental conditions: Since the rotational speed of wheel billet increases from 0.7; 1.3; 2; 3 rev/min, the K_{PBQU} coefficient decreases from 66.20, 60.69, 57.49, 8.06 and K_{PBT} coefficient also reduces from 76.26; 69.74; 66.88; 11.01. The difference between K_{PBQU} and K_{PBT} coefficient is from 9.05 to 11.80, especially in the sample M12 is only 2.95. However, both K_{PBT} and K_{PBQU} coefficient showed decreasing trend since the current increases. This represents for increase amount of plating CBN abrasive on surface of wheel body. However, when the rotational speed increases to 3 rev/min, the particle distribution was sudden fall off. This can be explained by the rotational speed increases to 3 rev/min, the thickness of the nickel plating metal for attachment the abrasive CBN is not enough to keep the abrasive. The abrasives on the wheel surface were easily peeling off with the wheel rotation leading to a small number of particles on the wheel surface. For sample M12, the disparity of K_{PBQU} and K_{PBT} was very small (2.95) which can be explained by the very small amount of CBN abrasive attached on the wheel surface which has less effect to the coefficient K_{PBT}. In M11 sample, the distribution of grains was observed not uniform like those in the sample M9 and M3. Thus, the rotational speed of the wheel body at 0.7 rev/min to 1.3 rev/min is appropriate.

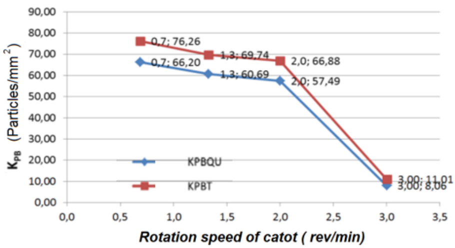


Figure 4.17. Relations of K_{PB} and the rotation speed of catot

4.2.3. Effect of composite plating time

Table 4.5 presents the experimental results and calculations related coefficient distribution of abrasive and thickness of the abrasive buried respected to the composite plating time (3; 5; 10; 15 minutes corresponds to the samples M17; M3; M1 and M8).

The SEM image in Figure 4.19 provides the distribution of the abrasive on the sample surface at a magnification of 50× to 500×. The dependence of the coefficient K_{PBQU} and K_{PBT} to plating time is shown on Figure 4.21. From the results, the following conclusions can be made:

The CBN particle distributed relatively evenly over the sample surface. However, in the sample M17, due to small composite plating time, t_m = 3 minutes, there was some areas with uneven distribution of abrasive as shown in Figure 4.19a. At longer plating time, the sample M8 (t_m = 15 minutes), some particles appeared to be overlap on the sample surface as observed in Figure 4.19d. Therefore, the appropriate plating time should be between 5- 10 minutes.

Table 4.5. Effect of composite Ni-CBN plating time to coating thickness and coefficients KPBQU and KPBT (T = 55 ℃, I = 3 A/dm2, nct = 0.7 rev/min)

No	Layer	Plating time	Calculated nickel–plated thickness not account abrasive grits		K_{PBQU}	K_{PBT}	$\Delta K_{PB} = K_{PBT} - K_{PBQU}$	Calculated nickel–plated thickness account abrasive grits	
			Individual layer	Embedded thickness				account K_{PBQU}	account K_{PBT}
		(min)	(µm)		(particles/mm²)			(µm)	
M17	L1	25	13,84	18,27	50,05	59,54	9,49	21,34	22,20
	L2	3	1,66						
	L3	30	16,61						
M3	L1	25	13,84	22,15	66,20	76,26	10,07	29,38	31,58
	L2	5	2,77						
	L3	35	19,38						
M1	L1	25	13,84	24,91	72,24	84,01	11,77	36,19	41,10
	L2	10	5,54						
	L3	35	19,38						
M8	L1	25	13,84	27,68	77,89	91,35	13,47	45,06	55,60
	L2	15	8,30						
	L3	35	19,38						

- At the same experimental conditions: composite plating time greatly affects to the distribution of CBN abrasive on the body surface. The amount of plated abrasives increases with time. When plating time of wheel body increased from 3; 5; 10; and 15 minutes, the K_{PBQU} increased from 50.05; 66.20; 72.24; 77.89 also K_{PBT} coefficient gradually increased from 59.54; 76.26; 83.61; 91.35.

Although K_{PBQU} and K_{PBT} coefficient can be differ from 9.41 to 13.47, but the relationship of K_{PBT} and K_{PBQU} coefficients to plating time shows that when increasing the plating time, the number of plated CBN abrasive on plated body surface increased.

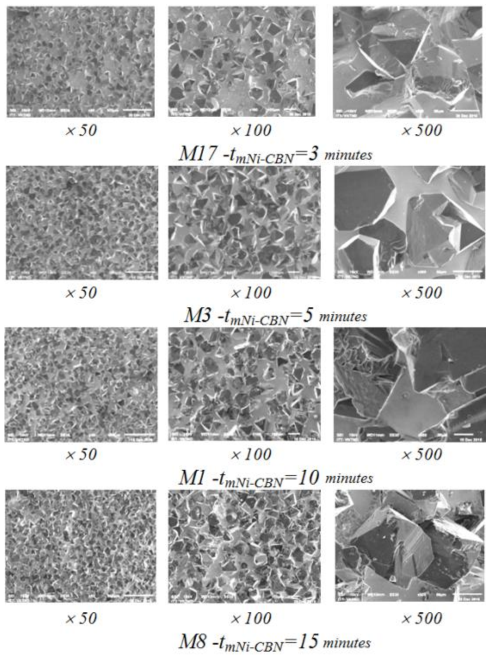


Figure 4.19. SEM images samples M17, M3, M1 and M8

4.2.4. Effect of the temperature of plating solution.

Table 4.6 presents the experimental results relating K_{PBQU}, K_{PBT} and burial thickness of CBN particles respected to the temperature of plating solution T = 50; 55; 60°C with samples M14; M3 and M13. Figure 4.23 present SEM images of the sample surface. Figure 4.25 show negligible influence of the temperature of plating solution to K_{PBQU} and K_{PBT}. From the these results, the conclusion can be seen:

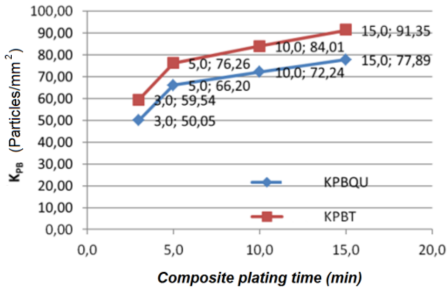


Figure 4.21. K_{PB} and plating time

Table 4.6. Effect of temperature of plating solution to the plating thickness and coefficient K_{PBQU} and K_{PBT} (i = 3 A/dm^2, n_{ct} = 0.7 rev/min, t_m = 5 minutes)

No	Layer	Temperature of solution (°C)	Calculated nickel–plated thickness not account abrasive grits: Individual layer (µm)	Calculated nickel–plated thickness not account abrasive grits: Embedded thickness (µm)	K_{PBQU} (particles/mm²)	K_{PBT} (particles/mm²)	ΔK_{PB} = K_{PBT}-K_{PBQU} (particles/mm²)	Calculated nickel–plated thickness account abrasive grits: account K_{PBQU} (µm)	Calculated nickel–plated thickness account abrasive grits: account K_{PBT} (µm)
M14	L1	50	13,84		63,20	74,23	11,03	24,28	25,81
	L2	50	2,77	19,38					
	L3	50	16,61						
M3	L1	55	13,84		66,20	76,26	10,07	29,38	31,58
	L2	55	2,77	22,15					
	L3	55	19,38						
M13	L1	60	13,84		65,29	75,86	10,57	24,55	26,07
	L2	60	2,77	19,38					
	L3	60	16,61						

- CBN particles distributed evenly on the surface coating. The temperature of plating solution in the range of 50-60°C did not significantly affect the distribution of the abrasive on the plated body surface.

-When the temperature of plating solution rises from 50; 55; 60°C, the coefficient K_{PBQU} changed from 63.20; 66.20; 65.29 while K_{PBT} varied from 74.23; 76.26; 75.86. The difference between K_{PBQU} and

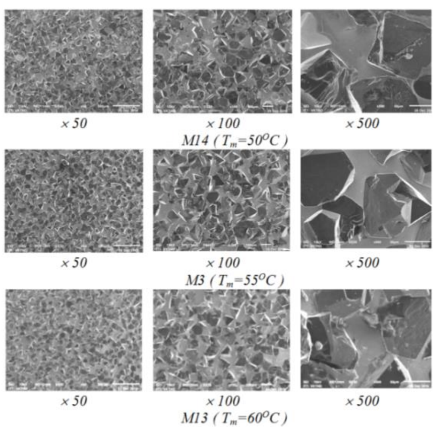


Figure 4.23. SEM images samples M14, M3,

K_{PBT} coefficient was from 10.57 to 11.03. The values of K_{PBT} and K_{PBQU} coefficient showed that the changes in plating temperature had very little impact to the distribution of CBN particle on the plated body surface.

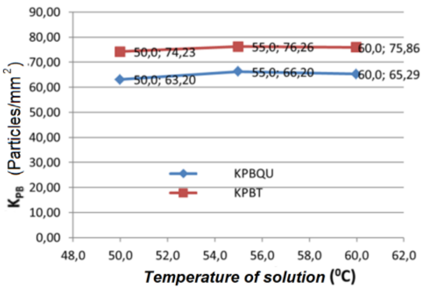


Figure 4.25. K_{PB} versus temperature of plating solution

4.2.5. Influence of multiple parameters simultaneously to the distribution of the abrasive particles in the coating.

4.2.5.1. Planning experiments simultaneously three factors

Based on the experiments above, the experiments were conducted to study the effect of multiple parameters simultaneously to K_{PBT}. The multiple of parameters were selected as follows: current density from 3-8 A/dm^2; the rotational speed from 0.7 to 1.3 rev/min; plating time range from 5 to 10 minutes.

4.2.5.2. Experimental results.

The results of experiments with influence of multiple parameters simultaneously are presented in Table 4.8.

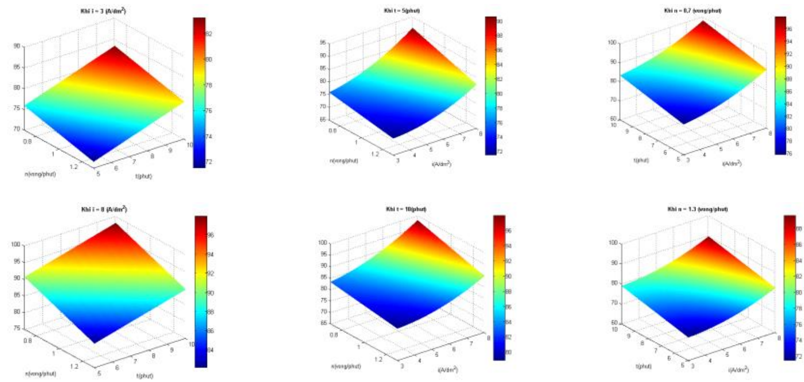
Table 4.8. The impact of three experimental parameters simultaneously to K_{PBT}

No.	Variable Code			Variable			K_{PBT}	
	A	B	C	n	t	I	K_{PBT1}	K_{PBT2}
1	-1	-1	-1	0.7	5	3	75.04	76.26
2	+1	-1	-1	1.3	5	3	70.96	69.74
3	-1	+1	-1	0.7	10	3	83.20	84.01
4	+1	+1	-1	1.3	10	3	79.12	79.93
5	-1	-1	+1	0.7	5	8	89.72	91.35
6	+1	-1	+1	1.3	5	8	81.57	83.61
7	-1	+1	+1	0.7	10	8	96.25	99.10
8	+1	+1	+1	1.3	10	8	87.28	88.91
9	-1	0	0	0.7	7.5	5.5	84.01	83.61
10	+1	0	0	1.3	7.5	5.5	78.71	79.12
11	0	-1	0	1	5	5.5	79.12	77.08
12	0	+1	0	1	10	5.5	86.46	84.01
13	0	0	-1	1	7.5	3	79.12	76.26
14	0	0	+1	1	7.5	8	90.54	92.17
15	0	0	0	1	7.5	5.5	83.61	81.16
16	0	0	0	1	7.5	5.5	79.12	81.57

4.2.5.3. Determination of the regression equation

Minitab 17.0 software is used to process experimental results, regression equation according to three variables is determined as:

$$K_{PBT} = 70.42 - 3.13\,n + 1.476t - 0.049i + 0.3586\,i^2 - 1{,}359\,n.i \quad (4\text{-}3)$$



a) K_{PBT} versus n and t *b) K_{PBT} versus n and t* *c) K_{PBT} versus I and t*

Figure 4.26. 3D Graph K_{PBT} versus various plating parameters

The 3D graphs which were draw based on the regression equation (4.4) represent distribution function of K_{PBT} versus various parameters (plating time, current density and rotation speed) as shown in Figure 4.26. In the regression equation, the coefficient of the rotational speed is -3.13 which means that when the rotational speed increases, the K_{PBT} decreases. The coefficients of the plating time is 1.476 showed that when the time increases, the K_{PBT} increases. Meanwhile the coefficient of the current density i is -0.049, the coefficient of i^2 is 0.3586. This shows the impact of current density with non-linear relationship. When the current density increases, the distribution of abrasive particles also increases. Also the interaction of two parameter (n and i) also has trend of reducing the coefficient K_{PBT} due to its negative coefficients. Through experimental results in graphs 4.26, following notices can be found:

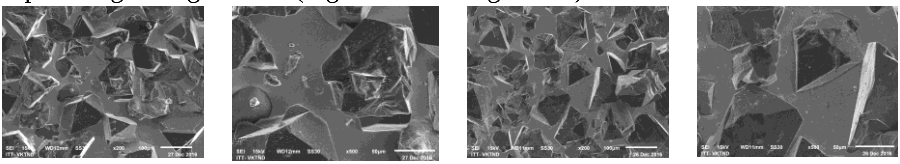
-In the experiment range, there were not the maximum and or minimum values of abrasives' distribution K_{PBT}. This is logical because in the experiment when the current and plating time increases and the rotation speed decreases, the K_{PBT} increase. However, the high value of K_{PBT} is preferred but it should be within a reasonable range. Because if the K_{PBT} is too high, there is stacking of the abrasive in the process that make weak bonding of the abrasive to the core layer, and to reduce chip evacuation and prevents the heat escape during grinding process. This has negative effect in the grinding zone in the cutting process.

- The regression equation in the study have implications in allowing predicted particles distribution, K_{PBT}, corresponding the set of experimental parameters. It also help to select a experimental parameter set when higher particles distribution is requested.

4.3. Evaluation of bonding strength and cutting properties of fabricated CBN grinding wheel

4.3.1. Observation of the bonding

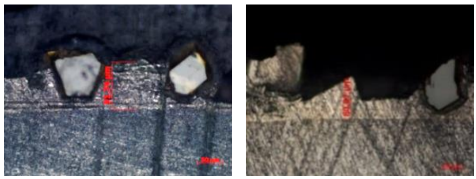
The level of bonding between CBN abrasive particles with metal core is determined through SEM images of the grinding wheel (Figure 4.28). The fabricated CBN grinding wheel shows a good bonding between the CBN abrasives and metal wheel. The grinding wheel surface is similar to those of Japanese grinding wheel (figure 4.1). Figure 4.29 presents observations through cross-sections which shows that CBN abrasive particles was buried partly, a good bonding between the metal plating layer and metal wheel without any delamination. The images of fabricated CBN grinding wheel surface (Figure 4.29) show no much difference to images of Japanese grinding wheels (Figure 4.3 and Figure 4.4).



a) M5 at 200x *b) M5 at 800x* *c) M7 at 200x* *d) M7 at 800x*

Figure 4.28. The surface of samples M5 and M7

The thickness of background nickel plating layer is about 12-17 µm. The depth of CBN particle penetrated is about 55 µm. Some abrasive particles were peeled off and left voids on the wheel surface



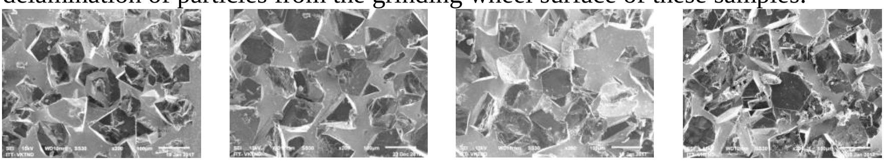
a) Form M5 b) samples M7

Figure 4.29. SEM cross-section images

To assess the strength level of the bonding between CBN abrasives and metal wheel, the grinding with fabricated CBN grinding wheel need to be examined to have accurate conclusions.

4.3.2. Assess the durability of the bond

Figure 4.31 shows SEM images of the sample surface M1, M2, M3 and M6 after 200 grinding passes with a cutting depth of 0.01mm. There was not any delamination of particles from the grinding wheel surface of these samples.



a) M1 *b) M2* *a) M3* *b) M6*

Figure 4.31. SEM image of grinding wheel surface after 200 cutting passes

By observing SEM images of grinding wheel surface without cleaning after grinding process (Figure 4.34), there were CBN abrasive involved in the cutting process and the piece of chip on. They were clear evidences for the cutting process of CBN abrasive particles. This also confirms that the bonding strength of nickel intermediate layer is durable enough to withstand the impact of the grinding forces.

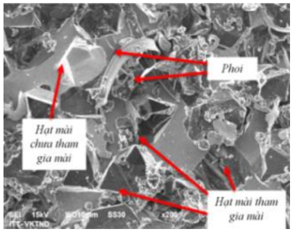


Figure 4.34. M2 after grinding (No cleaning)

4.3.3. Assessment of cutting properties

Assessment of cutting properties of CBN grinding wheel in two ways:

4.3.3.1. Assessment of cutting properties by cutting ability

The G-ratio is one of the commonly used criteria for evaluation of cutting ability of the grinding wheel. The assessment of the cutting ability of grinding wheel is done by comparison the actual amount of metal being cut experiments with amount of cutting metal in theory. Relationship between removed amount of workpiece and grinding passes is shown on Table 4.14 and Figure 4.35.

Table 4.14. Cutting thickness

Grinding pass	Grinding time (min)	Cutting thickness			
		M1	M2	M3	M6
100	15	0.998	0.998	0.999	0.998
200	30	1.997	1.997	1.999	1.997
300	45	2.996	2.994	2.998	2.997
400	60	3.996	3.993	3.997	3.996
500	75	4.995	4.989	4.996	4.995

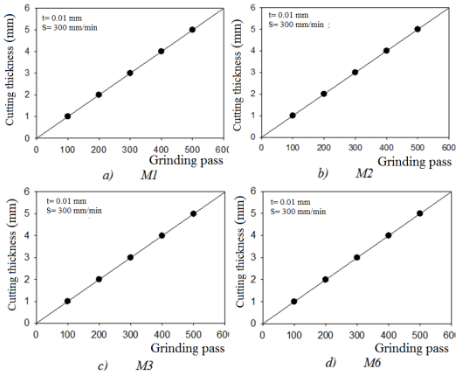


Figure 4.35. Relations between the amount of metal cutting and grinding the journey

The experimental results showed that the amount of metal being cut off at a increase rate linearly with the grinding passes of the grinding wheel. This also means that amount of removed material corresponding to feed rate in each grinding pass. This proved that fabrication grinding wheel has two important characteristics for any cutting tool: good sharpness and less wear during cutting process. With 75 minutes of grinding, metal thickness removed is 4.995 mm, 4.989 mm, 4.996 mm and 4.995

Figure 4.15. G-ratio of the samples

	M1	M2	M3	M6	Japan's
G	1430,96	649,66	1789,06	1430,96	1789,06

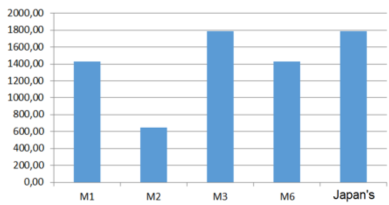


Figure 4.37. G-ratio of the samples

mm corresponding to sample M1, M2, M3 and M6 in comparison to the theory cutting thickness of 5 mm. This forecast that the working time of the fabrication grinding wheel is very high. The G-ratio is represented in Table 4.15 and Figure 4.37. As shown in Table 4.15, the G-ratio is very high (649.66÷1789.06). M2 grinding wheel has G-ratio at 649.66, lower than other samples. The reason can cause from high distribution of CBN abrasive particle (K_{PBT} = 99,1) leading some particles overlap (Figure 4.38) and easily peeled off. Therefore distribution of abrasive particle should be within a reasonable range.

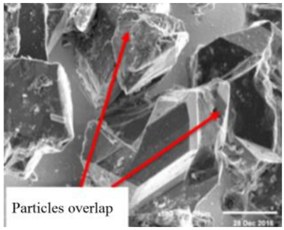


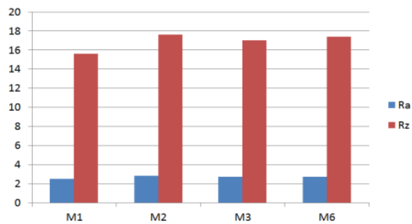
Figure 4.38. M2 before grinding

Compared to the Japanese grinding wheels, G-ratio of the fabricated grinding wheels is (0.8÷1) times, separate M2 only 0.36 times. This shows that the bond strength is sufficiently durable to hold the abrasive particle equivalent to Japanese ones.

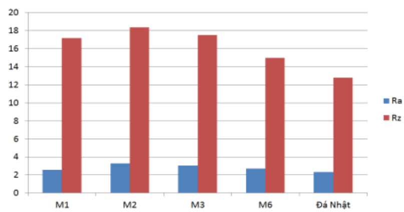
4.3.3.2. Assessment of cutting properties by surface roughness of workpiece

Table 4.16. Surface roughness

Sample	t=0.005 mm		t=0,01mm	
	Ra	Rz	Ra	Rz
M1	2,52	15,6	2,59	17,2
M2	2,84	17,6	3,27	18,4
M3	2,7	17,0	3,03	17,5
M6	2,75	17,4	2,72	15,0
Japan's			2,35	12,8



a) t = 0.005



b) t =

Figure 4.39. The surface roughness (Ra, Rz) after 200 grinding passes

The surface roughness of the workpiece is another indicator to assess the cutting ability of the grinding wheel. The surface roughness of the workpieces after 200 grinding passes are shown in Table 4.16 and Figure 4.39 with cutting depth of 0.005 mm and 0.01 mm and grinding wheel sample M1, M2, M3, M6 and Japanese grinding wheel. In both cutting conditions, the surface roughness of workpiece insignificantly changed. Surface roughness R_a varied from 2.5 to 2.84μm with grinding depth of 0.005 mm and from 2.72 to 3.27 μm with grinding depth of 0.01 mm. More importantly, the surface roughness with fabrication grinding wheel did not show much difference to the one obtained with Japanese grinding wheel (R_a

= 2.35μm). This is reasonable because the surface quality of Japanese grinding wheel is better than those of fabrication grinding wheels.

4.3.3. Overview assessment

From the experimental results and the discussion, it can be seen that:

The nickel metal bonding formed by EP is durable enough to hold the abrasive CBN from peeling off the grinding wheel surface under the effect of grinding forces.

The fabrication CBN grinding wheels is capable of good cutting performance with high G-ratio from 649.66÷1789.06. It can be applied in real production.

The surface roughness of workpiece with these grinding wheels (R_a: 2.5 ÷2.84μm with grinding depth of 0.005 mm and from 2.72 to 3.27 μm with grinding depth of 0.01 mm) is roughly equivalent to those with Japanese grinding wheel

CONCLUSION FOR CHAPTER 4

Based on the results of the study, following conclusion can be confirmed:

- This study has been identified the fabrication process of CBN grinding wheel by EP at Vietnamese manufacturing condition.

- This research has been fabricated the CBN grinding wheel using EP technology of the composite plating Ni-CBN with Watts solution. The research has identified effect of plating parameters (current density, plating time, temperature of plating solution and rotation speed of wheel body) to the distribution of the CBN abrasive particle on the surface of grinding wheel. When the current density, plating time increases and the rotation speed decreases, the abrasives' distribution increases. The effect of temperature of plating solution was insignificant to the distribution of abrasive particles. The appropriate current density in the range of 3-8 A/dm^2, suitable plating time of Ni-CBN composite layer of 5-10 minutes, rotating speed of wheel body from 0.7 to 1.3 rev/min, and the appropriate temperature of the plating solution from 50-60°C.

- The application of the experimental method has identified the regression function which describes the influence of three parameters simultaneously plating condition to the distribution coefficient of abrasive particle as (4-3):

$$K_{PBT} = 70.42 - 3.13\, n + 1.476t - 0.049i + 0.3586\, i^2 - 1,359\, n.i$$

Using this regression can predict the appropriate plating parameters for requested distribution.

- By observing study of the surface of the fabricated grinding wheel, cross-sections and grinding test, this study has confirmed that the nickel metal bonding formed by EP is durable enough to hold the abrasive from peeling off the surface of grinding wheel under the impact of grinding forces. The fabrication CBN grinding wheels is capable of good cutting performance with high G-ratio. It can be applied in real production. The surface roughness of workpiece with these grinding wheels is roughly equivalent to the those with Japanese grinding wheel.

CONCLUSION

With the goal of fabrication of CBN grinding wheel with metal bonding by EP method, the thesis has achieved the following specific results:

- For the first time in Vietnam, the study and manufacturing CBN grinding wheel with metal bonding by EP method with Watts solution has been successful.

The formula for distribution coefficient (K_{PBQU} and K_{PBT}) and the equation for determining the approximate plating thickness was established.

- To plate the composite Ni-CBN layer with large particle sizes (about 90 ÷ 106 µm) with a solution Watts, the manufacturing systems and fabrication equipment are designed with the horizontal wheel body (cathode) which was stability control rotational speed as well as control of other affecting technological factors (current density, plating time, temperature of plating solution) to the plating quality.

- Introducing the plating process of grinding wheel and selecting four technological parameters (current density, plating time, temperature of plating solution and rotation speed of wheel body) to study the influence of these technology parameters of the electroplating process to the fabrication process of CBN grinding wheel. The technological parameters were determined: current density in the range of 3-8 A/dm^2, plating time for Ni-CBN composite layer of 5-10 minutes, rotating speed of wheel body from 0.7 to 1.3 rev/min, and temperature of the plating solution from 50-60°C to ensures the uniform distribution and good adhesion of CBN grinding particles on the surface of the grinding wheel. To create the adhesion of CBN with nickel plated layer on steel substrate, performed three stage process is performed: plated lining, particle adhered plating layer and particle buried plating layer

- The mathematical model reflects the dependence of the distribution of abrasive particle to 3 technology parameters simultaneously in plating process as (4-3) are:

$$K_{PBT} = 70.42 - 3.13\, n + 1.476t - 0.049i + 0.3586\, i^2 - 1{,}359\, n.i$$

The model is accordance with the rules of the actual coating technology. Based on this model, the technology parameters can be predicted corresponding to distribution requirements.

- The cutting ability of CBN fabrication grinding wheel was tested over 500 grinding passes at grinding speed of 12.56 m/s, the cutting depth t = 0.01 mm of on the work materials with hardness from 63HRC. The grinding ratio is from 649.66 ÷ 1789.06 which confirmed nickel metal bonding layer formed by EP is durable enough to ensure the cutting process of the CBN fabrication grinding wheel.