Ultra Precision Machining of Machinable Ceramic by Electrolytic In-process Dressing

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ABSTRACT

In-Process Electrolytic Dressing is a constant pressure grinding method which produces less surface roughness and better flatness than other grinding systems. This technology provides dressing to CIB-Diamond Lapping wheels during the grinding process for continuous protrudent abrasive from super-abrasive wheels, so loading and glazing are disappeared apparently. Compared with conventional grinding, a significant reduction in grinding force was noted when In-Process Electrolytic Dressing was performed.

Ultra-precision machinability of the developed ceramics will be studied in the viewpoint of In-Process Electrolytic Dressing (IED).

For ultra-precision lapping machining, need to develop a ultra-precision lapping system, suitable metal bonded diamond wheel, and appropriate condition of ultra-precision lapping machining.
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Chapter 1. Introduction

1.1 Research background

In recent years, developments in the aerospace, information and communication, automotive industries require an advanced material of high hardness, chemical inertness, high thermal resistance, high-precision and low electrical conductivity in critical situation. Advanced material is used of metallic mold for mass production. Metallic mold requires a property of high hardness, tenacity, resists abrasion. Hence, require a high technology for machining. Moreover, a devices of semiconductor and a precision electronic have became a high function, have complicated on three dimension form, more require micro-device.

Therefore, Interest advanced ceramic has increase significantly in recent years due to their unique physical properties and due to significant improvements in their mechanical properties and reliability [1]. The advantages of ceramics over other materials include high hardness and its retention at high temperatures, light weight, chemical stability, and superior wear-resistance. Despite these advantages, the use of advanced ceramics in various applications has not increased rapidly due in part to
the high cost of machining these materials. The primary cost drivers in the
lapping of ceramics are low efficiency due to low removal rates, high
super-abrasive wheel wear rates, and long wheel dressing times. Decreasing Processing time and an improvement of manufacturing is very
importance like as ultra-precision machining, a high technology for
machining. In recently, many researchers haste developing a technology
of high efficiency and mirror-like surface. Ultra precision machining is an
importance factor that determine upon a surface of material, so, need a
many study.

Ceramics that be processed to general machining tool (high speed steel, hard
metal) is developed. It is what is call Machinable ceramic. BN-Ceramic(Si₃N₄,
AlN) used by stuff of Machinable Ceramic. The composite material of BN-
Ceramic(Si₃N₄, AlN) have a property of high thermal resistance, high hardness,
chemical inertness.

AlN-BN Ceramics easily machining because AlN-Ceramic raise a many
micro crack, AlN-BN mix AlN with h-BN that have property of thermal
expansion is a low, thermal conductivity is a high, thermal shock resistance is
superiority.

The traditional lapping pollute a environments, require high cost for mirror-
like surface, inefficient work. For mirror-like surface of Machinable Ceramic,
using super abrasive metal bonded wheel of more than 1000 grit size. The dressing of the super-abrasive wheel is difficult due to loading and glazing [2].

The technology of In-Process Electrolytic Dressing has been developed to solve this problem [3-5]. In-process electrolytic dressing is the method using electrolysis, where the worn abrasive grains are removed and new grains are caused to protrude from the wheel surface. This technology expects to elevation of processing and work efficiency.

1.2 Research Content

It has been well documented that the machinability of ceramic, hard steel and ferrite were poor, the tool wear was significant and the associated machining cost was thus high. As a result, the use of metal, resin, vitreous bonded diamond wheel in applications has rapidly increased [6-7]. Diamond, the hardest material, has become the primary abrasive for ceramic lapping applications.

The super-abrasive diamond wheels are able to produce mirror-like surfaces in these machinable ceramics economically using super-abrasive diamond wheels of more than 1000 grit size. The dressing of the super-abrasive wheel is difficult due to loading and glazing. In-process electrolysis dressing lapping was developed to solve the problem.
The in-process electrolysis dressing lapping essential elemental include: the electrolytic power source, metal bonded diamond lapping wheel, electrolytic coolant. The aim of this study is to determine the machining characteristics in terms of lapping wheel speed, machining time. Therefore, the in-process electrolytic dressing system for ultra-precision lapping was constructed and the application of electrolytic dressing was beneficial in obtaining a mirror-like surface when lapping ceramics.
In-process Electrolysis dressing (IED)

High efficiency
Mirror like surface

Machinable Ceramic

A processing enhance compare with ceramic

High efficiency
Ultra precision lapping
Manufacture enhance

Fig. 1.1 Research background.
Chapter 2. The Principle and Equipments

2.1 The mechanism of In-process Electrolysis Dressing

In-process electrolytic dressing is the method using electrolysis, where the worn abrasive grains are removed and new grains are caused to protrude from the wheel surface. Since it is possible to be ground by grains that are not worn, a machined surface with good quality is obtained. The bond material of the lapping wheel consists of cast iron, which has electrical conductivity. Supplying power to the metal bond, connecting the electrode with the cathode, and providing electrolyte between the anode and the cathode. Electrolyte between the metal bond and the electrode, and the metal bond is removed, being mostly ionized into Fe, Fe$^{2+}$ or Fe$^{3+}$.

$$\begin{align*}
\text{Fe} & \rightarrow \text{Fe}^{2+} + 2e^- \\
\text{Fe}^{2+} & \rightarrow \text{Fe}^{3+} + e^- \\
\text{H}_2\text{O} & \rightarrow \text{H}^+ + \text{OH}^- \\
\text{Fe}^{2+} + 2\text{OH}^- & \Rightarrow \text{Fe(OH)}_2 \\
\text{Fe}^{3+} + 3\text{OH}^- & \Rightarrow \text{Fe(OH)}_3
\end{align*}$$

At the cathode, the electrochemical reactions are the generation of hydrogen gas and the production of hydroxyl ions. The ionized Fe forms hydroxides, Fe
(OH)$_2$ or Fe(OH)$_3$. After these reactions have occurred the electrical conductivity of the wheel surface is reduced with the growth of an insulating layer.

Fig.1 shows a schematic of the IED lapping process. After truing, the wheel surface has a flat face (denoted by ① in Fig.1). A pre-dressing process using the electrolytic dressing method was required for the purpose of maintaining the protrusion of the diamond as an abrasive on the wheel surface (② in Fig.1). Since insulating materials are generated on the wheel surface during electrolytic dressing, caused by hydration or oxidation of the bonded material, electrolytic phenomena gradually is reduced and stabilized (③ in Fig.1). Excessive electrolysis is prevented by this generation of insulating layer and therefore completes the pre-dressing. After lapping with the pre-dressed wheel begins, the grains are worn and the insulating layer on the wheel surface is removed (④ in Fig.1). The wear of this layer causes an increase in the electro-conductivity on the wheel surface. The electrolysis then restarts and this insulating layer can be recovered (⑤ in Fig.1). The protrusion of the grains remains constant. This cycle persists during the lapping operation.
2.2 The manufacture method of metal bonded diamond wheel

2.2.1 The Cast-iron bonded diamond lapping wheel

For ultra-precision machining, choose suitable to processing condition lapping wheel, and worn abrasive grains are removed and new grains must be protruded. Therefore, the bond material of lapping wheel is a very important, must be chosen a bond material according to workpiece.

Three most popular lapping wheel-bonding systems are: metal, resin, and vitreous. The Cast-iron bonded wheel has the advantage to be as follows.

1) The cast-iron bonded wheel has a more hardness, brittle than copper bonded wheel and cobalt-bonded wheel.
2) Loading is reduced.
3) Dressing ability is better than a general wheel.
4) Grinding ratio is high.
5) The cast-iron bonded wheel has a self protrusion.
6) In-process electrolytic dressing is a possible.

The IED process requires the workpiece, in this case the diamond lapping, to be electrically conductive. Cast-iron is the bonding system that satisfies such requirement.

For ultra-precision lapping, required a cast-iron bonded diamond wheel.
2.2.2 the manufacturing processor of Cast-iron bonded diamonded wheel

Wheel is classified as according to the kind of abrasive. Aluminum oxide abrasive, silicon carbide abrasive, diamond abrasive, CBN abrasive.

The hardness of diamond abrasive is compared to them. Since tungsten carbide is almost as hard as aluminum oxide abrasive, it is impossible to use it for lapping tungsten carbide. Silicon carbide, which is slightly harder than tungsten carbide, has been used in the past for lapping carbide tools. Some silicon carbide lapping wheels may still be used for the purpose, although diamond lapping wheel are much more cost-effective when the lapping ratios of these two wheels are compared.

Diamond abrasive, cast-iron bonded powder and mechano-chemicla powder are needed to make a Cast-iron bonded lapping wheel. After mixing a three powder, put on metallic pattern. It was fabricated by hot-pressing under \(750^\circ\text{C}, 2\ \text{ton/cm}^2\). Fig. 2.2 show a manufacturing process, next picture show a detail process.
2.3 Experimental system and method

2.3.1 Experimental system

The IED system consist of a cast-iron bonded wheel, IED power supply, electrolyte, etc.

Fig.2.10-14 shows an experimental system. Wheel use a cast-iron bonded diamond wheel to be electrically conductive. An electric current in the form of a square pulse wave was supplied from the IED power supply to the anode and cathode.

It link a cast-iron bonded diamond (CIB-D) lapping wheel to positive pole, copper electrode to negative pole. A coolant was diluted with water to a ratio of 1:50 and used as electrolyte and coolant for the experiment. Electrolyte was supplied in between the lapping wheel and the electrode to start electrolysis.

The electrode, which is the cathode, is pure copper (purity 99%), covering 1/4 –1/8 of the perimeter of the lapping wheel and the metal bond of the wheel is the anode. The gap between the cast-iron bonded diamond lapping wheel and the electrode was adjusted to 0.4mm.

The IED-system has a retainer-ring to hold the work-piece and a jig to increase certain pressure on the work-piece. Therefore, surface roughness and flatness of the work-piece can be easily obtained.

Table 1 shows the specifications of the in-process electrolytic dressing lapping system. The IED-lapping system in this study was composed of a cast iron bonded diamond (CIB-D) lapping wheel, IEDs power supply, a special electrolyte and a workpiece. The CIB-D lapping wheel of a #4000 grit size was
Table 1 Specifications of In-Process Electrolytic Dressing Lapping System

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lapping Machine</td>
<td>Single-sided Lapping Machine</td>
</tr>
<tr>
<td>Lapping Wheel</td>
<td>Cast Iron Bonded Diamond Lapping wheel (CIB-D)</td>
</tr>
<tr>
<td></td>
<td>(Ø 380 X W25mm #4000 conc.100)</td>
</tr>
<tr>
<td>Power Supply</td>
<td>IEDS Power Supply</td>
</tr>
<tr>
<td>Electrolytic Fluid</td>
<td>Solution type(50:1)</td>
</tr>
<tr>
<td>Workpiece</td>
<td>Machinable Ceramic</td>
</tr>
<tr>
<td></td>
<td>(Si₃N₄, AlN: 0%, 10%, 20%, 30%)</td>
</tr>
</tbody>
</table>

2.3.2 In-process electrolytic dressing controller

The IED power supply’s band of peak current (Iₚ) is from 0 to 40A, and the pulse duration and pause are from 0 to 999µ. Analog current and voltage meters were constructed for the measurement of the dressing current and voltage.
Table 2 Specification of Controller

<table>
<thead>
<tr>
<th>function</th>
<th>specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Power source</td>
<td>DC Pulse</td>
</tr>
<tr>
<td>2 Current</td>
<td>0 - 30 A</td>
</tr>
<tr>
<td>3 Voltage</td>
<td>0 - 100 V</td>
</tr>
<tr>
<td>4 Peak Current</td>
<td>30 A</td>
</tr>
<tr>
<td>5 Time ON</td>
<td>0 - 999 µ sec</td>
</tr>
<tr>
<td>6 Time OFF</td>
<td>0 - 999 µ sec</td>
</tr>
<tr>
<td>7 Timer</td>
<td>0 - 9999 sec</td>
</tr>
<tr>
<td>8 Main Switch</td>
<td></td>
</tr>
<tr>
<td>10 (+), (-)</td>
<td></td>
</tr>
<tr>
<td>11 power</td>
<td>220V AC 3</td>
</tr>
</tbody>
</table>
**Fig. 2.1 Mechanism of IED lapping.**

1. After Truing
2. Dressing started
3. Dressing completed
4. IED stabilized
5. IED cycled

- Diamond abrasive
- Metal bonded powder
- Mechano-chemical powder

Mixing

Put a mixing powder to press die

Sintering in Hot press machine

Adhesion using electric bond

**Fig. 2.2 Manufacturing processor of metal bonded diamond wheel.**
Fig. 2.3 Metal bonded diamond pellet before press.

Fig. 2.4 Press.
Fig. 2.5 Put press die.

Fig. 2.6 Before press(1).
Fig. 2.7 Before press(2).

Fig. 2.8 After press.
Fig. 2.9  IED- System.

Fig. 2.10  Wheel and Electrode.
Fig. 2.11 Jig and retainer.

Fig. 2.12 Coolant nozzle.
Fig. 2.14 Controller of electrolytic.
Chapter 3. Machinable ceramic

3.1 The characteristic of machinable ceramic

Interest in ceramics has increased significantly in recent years due to their unique physical properties and due to significant improvements in their mechanical properties and reliability [8]. The advantages of ceramics over other materials include high hardness and its retention at elevated temperatures, light weight, chemical stability, and superior wear-resistance. Despite these advantages, the use of ceramics in various applications has not increased rapidly due in part to the high cost of machining these materials [9].

A new design method of ceramic composites was proposed, which applies to the design of machinable (Si$_3$N$_4$, AlN) ceramics.

Hexagonal boron nitride (h-BN), which has excellent machinability due to a plate-like structure similar to that of graphite, was combined with silicon nitride, alumina to improve machinability of composite. A machinable ceramic was designed and fabricated. At the same time, Si$_3$N$_4$, AlN/h-BN ceramic composites with such composition and structure design possess a variety of interesting properties such as thermal shock resistance, low friction coefficient, and erosion resistance to molten metals [10]. As the result of the increased h-BN content with soft and layered structure, composites can be machined using general tools. A variety of methods have been utilized to improve the machinability of Si$_3$N$_4$, AlN ceramics, including porous ceramics and microstructure design (controlling the ratio of Si$_3$N$_4$, AlN).

In order to combine the good machinability of h-BN and the excellent
mechanical properties of Si₃N₄, AlN at both room temperatures and high temperatures, a graded Si₃N₄, AlN/h-BN ceramic composite was researched in this study. The hardness of Si₃N₄/h-BN with 10% h-BN volume content is as high as 1000 kg/mm². Fig 3.1 shows the effect of h-BN content on the fracture toughness and hardness. Moreover, the material depth, which can be easily machined, can be designed by adjusting the thickness of h-BN layer according to requirement of the engineering application.

The material removal mechanism of Si₃N₄, AlN/ h-BN composite during machining seems to rely on the cleavage of layered boron nitride crystals. During machining, the cleavage of h-BN crystals localizes fracture of the composite on a microscopic scale and allows powdered chips to form easily, giving rise to good machinability. Fig 3.1 show Machining mechanism of machinable ceramics. Poor machinability and high machining cost prohibit the potential application of Si₃N₄,AlN ceramics.

Combining the excellent thermal and mechanical properties of Si₃N₄,AlN ceramics with good machinability of h-BN, a machinable of Si₃N₄,AlN /h-BN ceramics was designed and fabricated. Fig 3.2 show Probability distribution of h- BN platelet numbers of each specimen. It was shown that hardness of Si₃N₄, AlN /h-BN composite layer decreased with the increase of h-BN content, which is advantageous to the machinability of Si₃N₄, AlN /h-BN composites. At the same time, it is well known that the remarkable properties of Si₃N₄, AlN /h-BN are high corrosion resistance to molten metal, high thermal shock resistance and excellent machinability, while retaining relatively high strength. Thus, Si₃N₄,AlN /h-BN has a variety of applications in engineering field [10].
3.2 AlN-BN ceramics

Aluminum nitride (AlN) is considered to be a promising substrate and package material for high power integrated circuits because of its high thermal conductivity, low dielectric constant, thermal expansion coefficient close to that of silicon and high electrical receptivity [11]~[13].

Recently AlN-BN composite ceramics have been developed with excellent properties such as good machinability and high heat shock resistance, and they are expected to find application in various fields [14]~[16].

AlN (grade H, Tokuyama, Japan.: average particle size, 2.9 μm) was used as a starting material. Powders of AlN with h-BN (0 – 30 %), Y2O3 (3 wt%) were mixed by wet ball milling using MC jar, Si₃N₄ Ball (D 10mm, ethyl alcohol. After ball milling for 72h, To disperse whiskers homogeneously, ultrasonic dispersion and stirrer were use at the same time. Mixed powders were dispersed by ball milling for 2h, and then, dried for 3h at 100°C, were fabricated (content of h-BN: 0%, 10%, 20%, 30% ).

Hot-pressed compacted of (D 60mm, 5mm) were fabricated by hot-pressing under 30Mpa at 1800°C for 2h under an N₂ atmosphere.

Specimens of 3 X 4 X 36mm³ were cut out from the hot-pressed compact. The surfaces of specimens were grinded and/or polished with a 200 or 1200 mesh diamond wheel.

3.3 Si₃N₄ machinable ceramics

Machining is emerging as an inevitable requirement for flexible use of ceramics, especially for structural ceramics. However, extremely high hardness
of ceramics makes conventional machining very difficult or even impossible. In the past, a lot of researches have been focused on the improvement of ceramic machinability [19]-[22].

Generally, two methods were used in improving the machinability of ceramic materials. One method is to introduce a weak interface phase or layered structure material in matrix to facilitate crack deflection and propagation during machining. This method is named compound machinable ceramics, such as mica-containing glass-ceramic [23].

The other is structure-design method, which is to optimize machinability of ceramics by adjusting the distribution of phase, porosity and three-dimension macrostructure and microstructure, such as porous ceramic, graded machinable ceramics [24]. Fig. 3.3 show TEM images of Si₃N₄-BN based machinable ceramics. Hexagonal boron nitride (h-BN), which has excellent machinability due to a plate-like structure similar to that of graphite, was combined with silicon nitride, alumina to improve machinability of composite. A machinable ceramic was designed and fabricated. At the same time, Si₃N₄, AlN/h-BN ceramic composites with such composition and structure design possess a variety of interesting properties such as thermal shock resistance, low friction coefficient, and erosion resistance to molten metals.

Fig 3.4 presents the indentation strength as a function of indentation load. For monolithic Si₃N₄ the slope, obtained by the liner regression method, was 0.30, which implies that fracture toughness change little as the crack grew. However, for the Si₃N₄-BN composites, the slopes were approximately 0.2 indications that fracture toughness increased as the crack length increased. The
strength after indentation at 49 N for the composites containing 20 or 25-vol% BN was approximately 300 Mpa, which was higher than monolithic Si$_3$N$_4$ indented at 98N. It implies that the composites can be even stronger than monolithic Si$_3$N$_4$ after usual machining such as cutting or surface grinding since a much higher load is generally applied for machining of monolithic Si$_3$N$_4$ than the soft composites. R-curves, obtained from the data in the previous figure, for the Si$_3$N$_4$-BN composites as compared with monolithic Si$_3$N$_4$ are presented in Fig 3.5. For the monolithic Si$_3$N$_4$, fracture toughness rose rapidly at the relatively short cracks and did not increase much thereafter. On the other hand, the Si$_3$N$_4$-BN composites showed slowly rising R-curves. Thereby, fracture toughness was low initially, but as the crack grew, fracture toughness was low initially, but as the crack grew, fracture toughness increased and became even higher than that of the monolithic Si$_3$N$_4$-BN when the crack was longer than 600[$\mu$].

$\alpha$-Si$_3$N$_4$ was used as a starting material, added a 8mol% Y$_2$O$_3$ –6mol%Al$_2$O$_3$. Powders of Si$_3$N$_4$ with h-BN ( 0 – 30 %), Y$_2$O$_3$ (3 wt%) were mixed by wet ball milling using MC jar, Si$_3$N$_4$ Ball ( D 10mm, ethyl alcohol. After ball milling for 72h, To disperse whiskers homogeneously, ultrasonic dispersion and stirrer were use at the same time. Mixed powders were dispersed by ball milling for 2h, and then, dried for 3h at 100°C, were fabricated (content of h-BN: 0%, 10%, 20%, 30% ).

Hot-pressed compacted of (D 60mm, 5mm) were fabricated by hot-pressing under 30Mpa at 1800°C for 2h under an N$_2$ atmosphere.

Specimens of 3 X 4 X 36mm$^3$ were cut out from the hot-pressed compact. The
surfaces of specimens were grinded and/or polished with a 200 or 1200 mesh diamond wheel.
Fig. 3.1 Machining mechanism of Machinable ceramics.

Fig. 3.2 Probability distribution of h-BN platelet numbers of each specimen.
Fig. 3.3 TEM images of Si$_3$N$_4$-BN based machinable ceramics.

Fig. 3.4 Indentation strength vs indentation load of Si$_3$N$_4$-BN based machinable ceramics.
Fig. 3.5 R-curves of Si$_3$N$_4$-BN based machinable ceramics.
4.1 Experimental condition

The gap between the cast-iron bonded diamond lapping wheel and the electrode was adjusted to 0.4mm. Electrolyte was supplied in between the cast-iron bonded diamond lapping wheel and the electrode to start electrolysis.

A coolant was diluted with water to a ratio of 1:50 and used as electrolyte and coolant for the experiment. Voltage during the pre-dressing of a wheel under electrical conditions: peak-current (Ip) 25A, pulse-time (τ on/off) 20μs. The IED-system has a retainer-ring to hold the work-piece and a jig to increase certain pressure on the work-piece.

This study uses Si₃N₄, AlN ceramics with additive h-BN (0 ~ 30%), it was lapping according to speed, time. After lapping, the workpieces were measured using the Tayler-Hobson surface roughness measurement instrument. Fig 4.1 shows a Measurement of surface roughness.

4.2 Electrolytic characteristics of pre-dressing

Before the lapping process, the lapping wheel must be done with truing and electrically pre-dressing.

Truing is carried out so that the initial eccentricity is reduced to a level
comparable with, or less than that of, average grain size of the wheel. Therefore, truing is very important when ultra-precision lapping is performed with a micro-grain size of the wheel.

It had a diameter of 31mm and was truing by a #325 lapping wheel before this experiment. After truing, Pre-dressing, when protrusion of the grains is achieved, which is essential for proper lapping operation. the pre-dressing was carried out in conditions of peak-current(Ip) 25A, pulse-time (τ on/off) 20μs, and a machining-time of 120 minutes. Fig. 4.2 shows the change of current and voltage during the pre-dressing of a wheel under electrical conditions. Results showed that the current values were sharply decreased after 5 minutes while voltage values increased. After 13 minutes, both the current value and the voltage value were maintained consistently. The reason for these changes is a result of the oxidized layers being produced according to passing dressing time. They negatively influence the electrolytic behaviors. Not only is there the conductivity between the lapping wheel and electrode but also there is a current value decrease, while the voltage value increases.

4.3 The processing characteristic of Si₃N₄-BN ceramics
Si₃N₄-BN ceramics is processed in the experimental condition (4.1 experimental condition). Si₃N₄-BN ceramics contents as each h-BN (0%, 10%, 20%, 30%), measure a surface roughness of Si₃N₄-BN ceramics at interval 5 minute.

Traditional processing has a loading, glazing, but IED-lapping achieve a
protrusion of grain; therefore the surface roughness is decreased.

The surface roughness is increased according to h-BN content.

Ceramic (h-BN is not contained) is a good surface roughness according to increase a processing time, but machinable ceramic (according to increase h-BN) is an inferior surface roughness. (Fig 4.3 – 4.7)

4.4 The characteristic of AlN-BN machinable ceramic

This study present to increase a surface roughness according to increase h-BN content. Fig 4.8 –4.11 is a graph and result of AlN-BN ceramic in the identical experimental condition of Si$_3$N$_4$-BN ceramics.

As a result, Ceramic (h-BN is not contained) is a good surface roughness according to increase a processing time, but machinable ceramic according to increase h-BN is an inferior surface roughness.

4.5 Changes of surface roughness according to lapping wheel speed

Generally, Surface roughness is decreased according to elevate a wheel speed.

This study experiments the surface roughness of machinable ceramic according to wheel speed.

Fig. 2.11 show a surface roughness according to wheel speed.

As the lapping wheel speed increases, the surface roughness is better. The reason for phenomenon is a result of the decreasing lapping resistance as the
lapping speed increases. the application of in-process dressing has an effect on improvement of surface roughness.

The surface roughness decrease to Ra = 0.2μm. There is a mirror-like surface formation in the ultra-precision lapping of ceramics.

**4.6 The experimental result**

Ceramic (h-BN is not contained) is a good surface roughness according to increase a processing time, but machinable ceramic (according to increase h-BN) is an inferior surface roughness.

It implies that the machinable ceramics can be even stronger than ceramics after usual machining such as cutting or surface lapping since a much higher load is generally applied for machining of machinable ceramics than the soft composites. R-curves, For ceramics, fracture toughness rose rapidly at the relatively short cracks and did not increase much thereafter. On the other hand, the machinable ceramics showed slowly rising R-curves. Thereby, fracture toughness was low initially, but as the crack grew, fracture toughness was low initially, but as the crack grew, fracture toughness increased and became even higher than that of the Si₃N₄-BN when the crack was longer than 600μ.

Relative density(Ds) is decreased according to increase h-BN, Si₃N₄ monolith and h-BN(0-20%) showing a theoretical densification, h-BN 30% shows a densification of 96.7%.

According to increase h-BN, Crack easily grew and density is decreased, machining is better, but it is difficult that lapping and grinding.

Fig 4.12,13 shows SEM photo, according to increase h-BN, present that crack
is increased, and that separation of particle is increased.
Fig. 4.1 Measurement of surface roughness.

Fig. 4.2 Electrical behavior of pre-dressing.
Fig. 4.3 Surface roughness of Machinable Ceramic(Si₃N₄ BN 0%).

Wheel Speed = 70rpm
Ip = 40A,
Ton on/off = 20s
Weight=2.5Kg

Fig. 4.4 Surface roughness of Machinable Ceramic(Si₃N₄ BN 10%).

Wheel Speed = 70rpm
Ip = 40A,
Ton on/off = 20s
Weight=2.5Kg
Fig. 4.5 Surface roughness of Machinable Ceramic(Si₃N₄ BN 20%).

Fig. 4.6 Surface roughness of Machinable Ceramic(Si₃N₄ BN 30%).
Fig. 4.7 Comparison of surface clarity (Si$_3$N$_4$ 10%).
Fig. 4.8 Surface roughness of Machinable Ceramic (AlN- BN 0%).

Wheel Speed = 70rpm  
Ip = 40A,  
Ton on/off = 20ìs  
Weight = 2.5Kg

Fig. 4.9 Surface roughness of Machinable Ceramic (AlN- BN 10%).

Wheel Speed = 70rpm  
Ip = 40A,  
Ton on/off = 20ìs  
Weight = 2.5Kg
Fig. 4.10 Surface roughness of Machinable Ceramic (AlN- BN 20%).

Fig. 4.11 Relationship between Surface roughness and Lapping (AlN- BN 10%).
a) BN 0%

b) BN 10%
c) BN 20%

Fig. 4.12 SEM of Machinable Ceramic (Si$_3$N$_4$).

a) BN 0%
3) BN 20%

Fig. 4.12 SEM of Machinable Ceramic (AlN).
Chapter 5. Conclusion

This paper studies the ultra-precision lapping of machinable ceramic by In-process electrolytic dressing. The result of study describes a conclusion.

1. The ceramic that not contain a h-BN present a surface roughness better than the ceramic that contain a h-BN, The longer lapping time was, the better a surface roughness was, and the greater wheel speed was, the better a surface roughness was.

2. The ceramic that contain a h-BN present a good surface roughness at 10 minute (lapping time). After 10 minute (lapping time), the surface roughness is not improved.

3. According to increase the h-BN of machinable ceramic, surface roughness is increased. Because h-BN content was increased, crack easily grew and density is decreased. It is caused that lapping and grinding is difficult.
Summary

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**Reference**


