Influence of surface modification by blast polishing method on the cutting performance of carbide tool
(超硬ツールの切削特性に及ぼすブラスト研磨法による表面改質の影響)

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Doctor of Engineering

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Abstract

Nowadays, the carbide cutting tools are widely used due to its excellent in heat and wear resistance and has the ability to withstand rigorous operating under high speeds conditions. Following the trend, the CNC grinding machine has advanced significantly which enables manufacturers to produce the cutting tool with more complex and sophisticated shapes easily. As a result, competition becomes intense in these field. Therefore, research on surface modification technology has gathered a lot of interest, which could ultimately improve machining performance from viewpoints other than tool geometry. Several research on the surface modification on the cutting tool surface had been conducted in order to improve the cutting tool performance and durability. A lot of method had been researched and reported including surface modification by implanting a textures on the surface as well as by mirror polishing the tool surface.

The blast polishing process is one of surface modification technologies favorably applied to the carbide cutting tools due to its excellent ability to polish a complex curve surface of the cutting tool, which is known to be a difficult processing, and improve the surface property of materials effectively. However, the blast polishing process has a limited information that theoretically explains its polishing mechanism. The relationships between the polishing parameters to the polished surface properties were also unknown. Therefore, as the first part of this thesis, the investigation of the polishing mechanism of cemented carbide using the blast polishing process is conducted by clarifying the relationship of the factors related to this polishing and the polished surface condition. Moreover, fewer cases had been reported regarding the influence of the blast polishing process to the cutting tool performance when actually applied this process to the cutting tools surface. Therefore as the second part of this thesis, the influence of surface modification by the treatment using blast polishing process to the cutting performance of the cutting tool is investigated. For this purpose, the conditions of grinding mark textures on the cutting tool surface is controlled and modified by the treatment using blast polishing process. And, the cutting tool performance is access by evaluating the improvement of the adhesion resistance on the tool surface as well as the improvement of lubricant fluidity and chip evacuation by measuring the cutting force relation with the drilling time and drilling depth.

In the first part of this thesis, which is regarding the study of polishing mechanism of the blast polishing process, it has been clarified that a smooth surface finish can be achieved easily and quickly by injecting the polishing media at the highest injection speed of 59.5 m/s, under injection angle of 45 deg. with water content of 30%.

Regarding the study of optimal surface property for the drill by surface modification using blast polishing process, it was clear that a different surface conditions is required in each part of the cutting tool flute surface in order to maximize the potential of the cutting tool. The cutting tool performance is shown to increase by leaving grinding mark textures on the rake face and smoothest the guide flute surface. This is because each flute surface parts function differently due to different work environment during the cutting process. The part near the cutting edge of the flute surface, the rake face work environment is more severe because this surface come to direct contact with the work piece. The chip is generated in this area thus the adhesion formation likely to occur. Therefore, the texture on the rake surface helps to reduce the real contact area between the surface and the work piece by providing a reservoir for the lubricant to retain inside it during the sliding to reduce the friction at the interface. Thus, the adhesion resistance is increased.

Furthermore, for the guide flute surface which is the major part of the drill surface. It main work function is to allow the excess of lubricant inside the hole to reached the rake face and also to provide an exit path for the chip generated inside the hole to evacuate. Its work environment is not as critical as the rake face and the adhesion is less likely to occur on the surface. Therefore the condition of the guide flute must be smooth polished surface to reduce the friction on the surface and increase the fluidity of the lubricant. As a results, lower cutting force is obtained and delaying the rise of the cutting force during the drilling process.

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1. Introduction

1.1. Background

In recent years, due to the diversification of user needs, the number of variation for each type of required product increased and eventually effect the number of production. To address these changes and corresponds with the specifics demand of the product, the mass production of one type of product is now changing and replaced by the variety variable production[1]. Therefore, the construction of machining technologies that have flexibility to correspond to each machining technique is required to accommodate the production of the variety variable product. One of the machining technologies effected by these demands are the cutting machine where of high speed cutting process have been approach recently. The advantages of this approach is the improvement of the shape and surface finish accuracy and processing efficiency[2]. However this approaches has been question to lowering the cutting tool life due to the rise of cutting edge temperature during the cutting process.

In respond to above problem, the demands for better cutting tools has increased. Nowadays, the carbide cutting tools are widely used due to its excellent in heat and wear resistance and the ability to withstand rigorous operating under high speeds conditions. Moreover, with the spread of the usage of these cutting tools, the need of producing these tool in high efficiency has increase. For this purpose, the CNC grinding machine has advanced significantly which allowing the production of the cutting tool with more complex and sophisticated shapes easily[3]–[5]. As a result, competition becomes intense among the developers of cutting tools. Consequently, the manufacturing sector faces great opportunities and challenges in this regard.

In order to compete in this industry, research on surface modification technology has gathered a lot of interest. Surface modification technology is as a way of refining and modifying the final finished surface of the cutting tool to allow simultaneous gains in energy efficiencies, increase their anti-adhesion performance, and reduce production cost. In the study of the development of micro and nanoscale textures on the cutting tools surface, it was reported that micro and nanoscale textures significantly improve the anti-adhesiveness and lubricity of the cutting tool[6]–[12]. In the study of surface roughness influence to the adhesion strength of the coating, it was revealed that lower surface roughness increases the coating adhesion strength on tool surface[13], [14]. Another study showed that the coating layer improves wear resistance and increases the cutting tools performance[15]. Another surface modification technique is by mirror polished the cutting tool surface. It has been reported that this method improves the chip evacuation and also reduces the cutting force[16], [17]. Hence, final finished quality of the cutting tool surface was proven to have a large influence on the cutting performance.

1.2. Blast polishing process

Since most of the cutting tools are made from a high hardness grade material and often with complex geometry, it is difficult to reduce the cost and processing time when preparing the tool in the final finishing process. For that reason, a finishing technology that requires short processing time in polishing a complex geometry is required. The blast polishing process focused on this study is one of the surface modification technologies that can fulfill the needs of the aforementioned field.

Blast polishing is a general term for a polishing process using an abrasive comprising of a viscoelastic core material covered with an abrasive grain (hereafter referred to as polishing media) and a blasting device similar to a shot blasting machine[18], [19]. Figure 1-1 shows the schematic diagram of a blast polishing machine operating system and a diagram of the abrasive grain behavior showing a comparison between a conventional blasting method and the blast polishing method. The polishing media was accelerated by the centrifugal force of the impeller together with compressed air and blasted onto the work piece surface. At the point of collision, the polishing process was performed when the polishing media deforms to mitigate its impact energy and slides onto the work surface[20]. As a result, this process produced a mirror-finished surface, which was different from the surface acquired by the conventional blasting method[21]–[23]. It was also reported that with this blast polishing method it is possible to polish a tool with complex shaped surface and remove droplets on the coating layer of the tool surface[24]–[26]. Since the polishing media is a viscoelastic water containing type, the chip, and the dust generated during the polishing will adhere to the polishing media, thus, a clean and feasible polishing process is created without deterioration to the working environment.

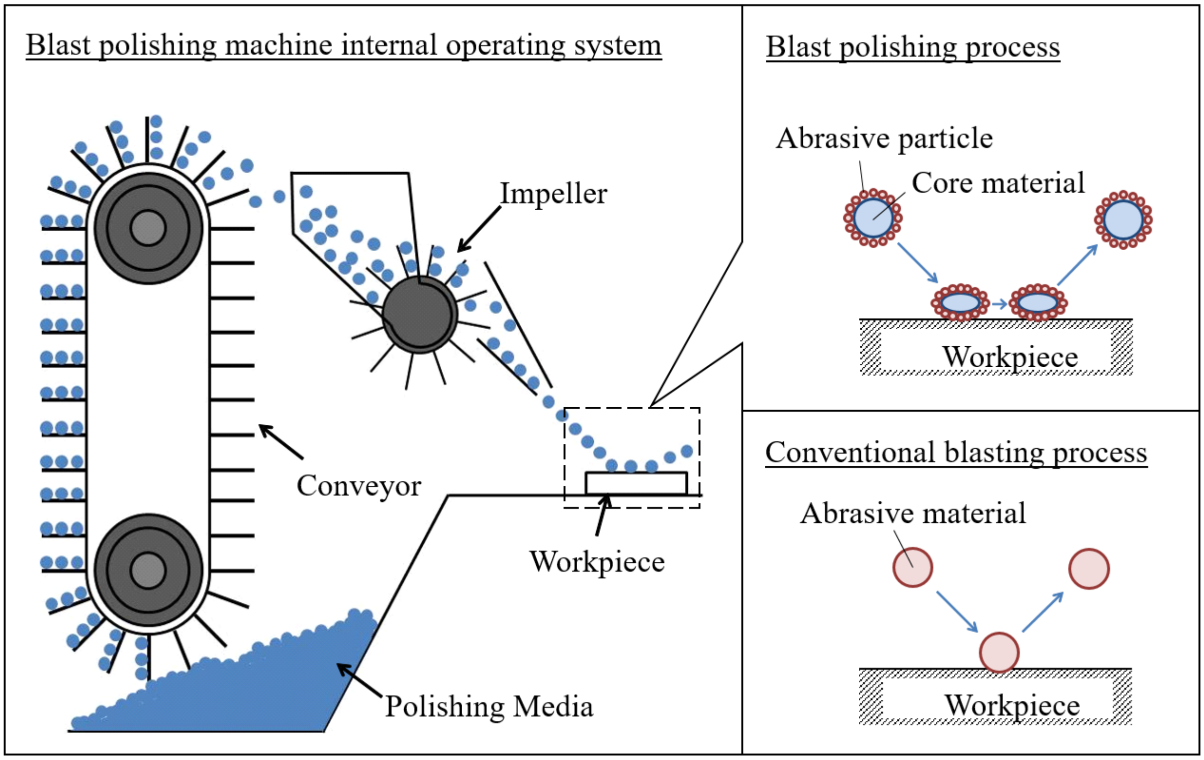


Figure 1-1 Schematic diagram of blast polishing machine and the comparison of the blast polishing process with the conventional blasting process.

Nevertheless, while with such excellent features, the blast polishing process still has an unresolved issue. There is limited information that explains the polishing characteristics of this process theoretically and a guideline of how to optimize and achieve high polishing efficiency using this process has not yet been clarified. The relationships between the polishing parameters to the polished surface properties were also indistinct. Hence, operators using this process are often forced to spend a significant time to determine the proper settings to achieve an ideal final surface condition[18]–[26]. Therefore, as the first part of this thesis, a study was carried out to clarify the polishing characteristics of the blast polishing process on the cemented carbide substrate by investigating the relationship of the factors related in this polishing process to the polished surface condition.

1.3. <u>Cutting tool surface modification to improve cutting performance</u>

The demand of aluminum alloy in automobile and aerospace industries has rapidly increased. This is due to its light weight property and high corrosion resistance. However, aluminum alloy has a low melting point and high ductility. Therefore in cutting process, aluminum chips severely adhere to the surface of the cutting tool and cause deterioration of chip evacuation that increases the cutting force, often leads to tool breakage. To address this problem cutting fluid is applied to provide lubrication and also to reduce the cutting temperature which can improve tool life to some extent. Despite these advantages, the cutting fluids have been questioned lately, due to the several negative effects they cause. For example, cutting fluids may damage soil and water resources, causing serious environmental degradation when inappropriately handled. In addition, the costs related to cutting fluids represent a large amount of the total machining costs. Therefore, the cutting fluid usage reduction is desirable. Dry machining process, without the use of cutting fluids satisfies the aforementioned circumstances, however the dry machining of aluminum alloy has proven difficult due to aluminum's adhesion to the drill. The chips severely adhere to the drill, and create obstacles for chip evacuation through the drill flutes.

The challenge is to minimize the adhesion of aluminum to the drill. In order to impart functions of anti-adhesion to the cutting tool, researchers are focusing on the tool surface modification, such as the development of the micro texture on the tool surface using laser technology[6]–[10]. These textures have been successful in improving the anti-adhesion by the reduction of real contact area and storage of the lubricant. However, these micro texture implantations are time consuming and also increase the production cost.

In the second part of this thesis, the development of the micro texture by controlling the grinding mark condition, which already exist on the tool surface is conducted by using the blast polishing treatment. Figure 1-2 shows the condition of grinding mark textures on the cutting tool surface. This grinding mark was left by the grinding machine during the production of the drill. In order to investigate the optimum surface condition to increase the adhesion resistance to the drill, these grinding mark is modified by the treatment using blast polishing process. It is thought that the grinding mark height as well as concave and convex shape can be controlled by adapting the most effectives polishing parameters in the blast polishing process which was revealed in the first part of this thesis.

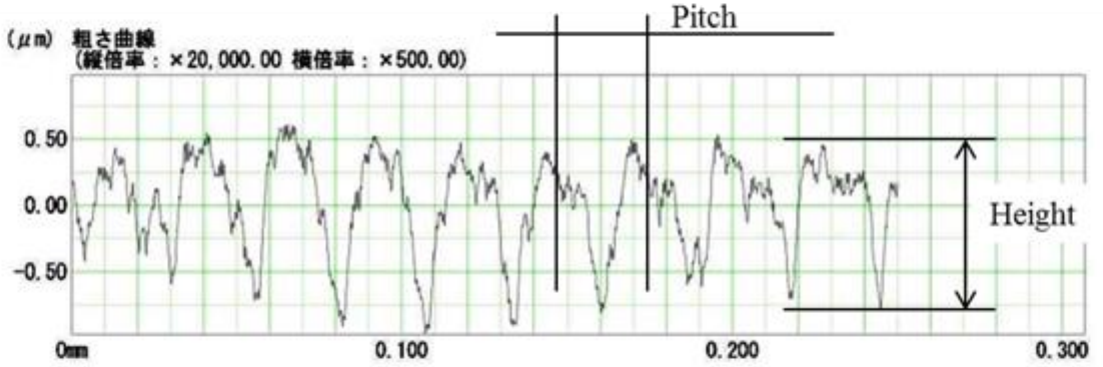


Figure 1-2 Condition of grinding marks on cutting tools.

The cutting performance of untreated and treated drill are evaluates during drilling the aluminum alloy, ADC12 in flooded condition using external coolant. The drilling performance was assessed by measuring the cutting force generated during drilling and by measuring the cumulative mass of the adhered aluminum after the drilling process.

1.4. Research objectives

In this thesis, two main issues are focused. One is to reveal the polishing mechanism of the blast polishing process and second is to investigate the influences of this process to the cutting tool performance by surface modification.

For the first issue, the main purpose is to theoretically clarify the mechanism of the blast polishing process and also to investigating the relationship of the factors related in this polishing process to the polished surface condition. The aim is to be able to explain in detail about the factors that influences in the blast polishing, such as the optimal degree of the injection angle that influence in kinetic energy distribution and also to clarify the optimal injection speed for high polishing efficiency. As well as to explain the factor of the polishing media water content to its viscoelasticity characteristics that was thought to be one of the factor that contribute to the high polishing efficiency of this process.

For the second issue, it was regarding the surface modification method on cutting tool surface. There are two critical point regarding this method is investigated which is a method by surface texturing[6]–[10] and a method by mirror polished the surface[16], [17]. A complete contradictory method but both has reported to improve the cutting tool performance. Therefore it is important to investigate both method because it is believed that a different surface condition is required for the specific part of the cutting tool because each particular parts has its own particular role and function independently. And, by the combination of these parts finally the cutting tool performance can be increase. Lastly, it is thought the grinding mark textures increase the adhesion resistance of the cutting tool. Therefore an investigation to study the adhesion behavior on the grinding mark textures is required as the evidence to support this consideration.

1.5. Scope of the thesis

This thesis consist of eight main chapters. Each chapter are introduced briefly and summarized as below:

- **First chapter** (**Introduction**), is the introduction which summaries all the content of this thesis, research background, and research purpose.
- **Second chapter** (**Experimental apparatus & experimental procedures**), describe the experimental and evaluation method in this study.
- **Third chapter** (**Effect of several factors in blast polishing process on surface condition of cemented carbide**), the factors of polishing media injection speed, injection angle and water content was investigated to study the influence of these factors on surface condition of cemented carbide substrate by the relations of polishing time and surface roughness value.
- **Fourth chapter** (**Polishing mechanism on cemented carbide substrate by blast polishing process**), the polishing mechanism on cemented carbide substrate by blast polishing process is investigated and clarified.
- **Fifth chapter** (**Study on optimal surface property of carbide drill for aluminum alloy cutting**), the

drill flute surface was treated using the blast polishing process by choosing the most effective polishing parameters that has becomes clear in the previous chapter. This chapter purpose was to reveal the optimal surface property of the drill flute surface in order to increase it adhesion resistance and to reduce the cutting force during the cutting.

❖ **Sixth chapter** (**Effects of grinding mark texture to the adhesion behavior of aluminum alloy**), further investigation of the function of the grinding mark in reducing the cutting force and increase the adhesion resistance is conducted on order to provide strong evidence for the consideration of the grinding mark function in the previous chapter.

❖ **Seventh chapter** (**Conclusion**), which is general conclusion of this thesis and its contribution to the academic sectors and to the industrial sectors.

❖ **Eighth chapter** (**Future perspectives**), describing the future plan and prospect of the results obtained in the present study.

2. Experimental apparatus & experimental procedures

2.1. Specimen

2.1.1 Work piece

Cemented carbide substrate is used as the work piece in this research. Table 2-1 shows the mechanical properties and chemical composition of the work piece carbide material. Note that the materials value shows in the table is the standard value revealed by the manufacturer and this material grade is applied to produce carbide drill which is commercially available in the market. Figure 2-1 shows the micro structure of carbide material. What appears to be a silver square-shaped is a WC grains, the black part fills between the WC grains is a binder phase of Co.

Table 2-1 Mechanical properties and chemical composition of carbide material.

Grain size of WC [µm]	Hardness [HV]	Bending Strength [GPa]	Composition [wt%]	
			WC	Co
0.8	1640	3.8	Bal.	10.0

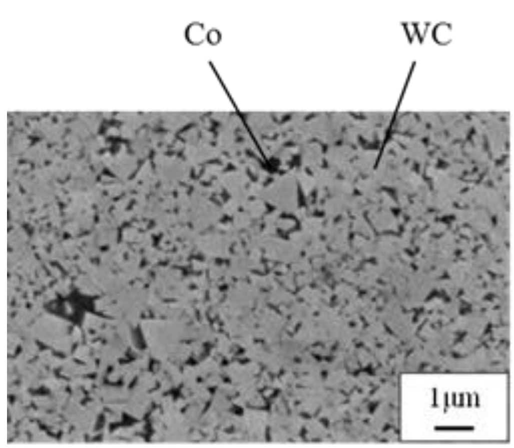
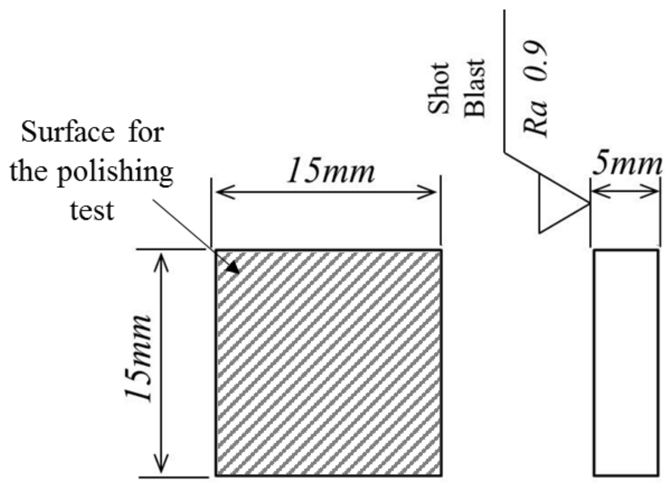


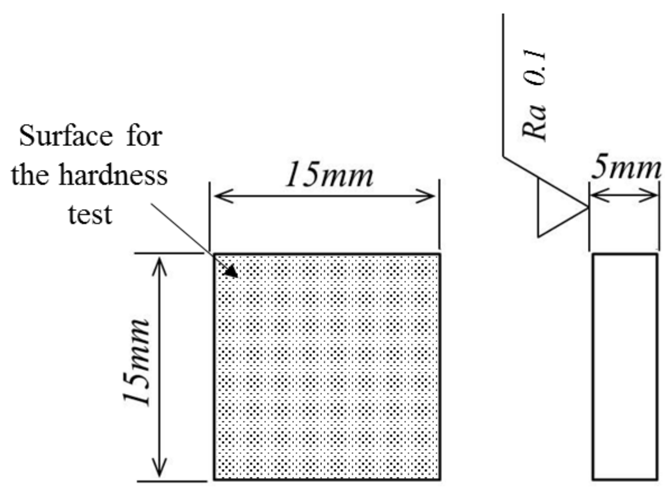
Figure 2-1 Micro structure of carbide material.

2.1.2 <u>Pretreatment method of the work piece surface</u>

Figure 2-2 shows the work piece geometry for the carbide substrate. The substrate size is set to 15mm×15mm×5mm to make sure that the entire polishing region polished by the polishing media can be easily distinguished for the evaluation purpose.



(a) For the normal polishing test



(b) For the measurement of hardness on polished surface

Figure 2-2 Geometry of work piece.

The surface of the work piece is pre-treated using shot blast machine made by Shintokogyo, Ltd.: MY-30 with the abrasive steel: GH-10, in order to achieve the surface roughness, Ra around 0.9µm, Figure 2-2 (a). This surface roughness is the surface roughness of the carbide drill flute surface which is commercially available in the market, which was set to get the basic knowledge of polishing the actual tool surface. Also, for the measurement of the hardness of the process surface, the work piece surface is finished by buffing method, Figure 2-2 (b). The purpose of this measurement is to evaluate the occurrence of work hardening after being polished with the blast polishing method. The surface roughness after buffing is approximately Ra 0.1 µm which is close to the surface roughness saturation values obtained in a blast polishing experiments described below.

2.2. Polishing media

2.2.1 Details of the polishing media

The polishing media used in this study was developed by Yamashita Works Co., Ltd. This polishing media comprised of two main materials being the core material, Multi-cone (made from gelatin comprising of grain size around 0.5-2.0 mm which has viscoelasticity characteristics in absorbed water condition) and the abrasive grain, Multi-Powder (comprise of diamond and SiC with the particle size of #3000, about 5µm in diameter, functioning as the cutting edge for the polishing media). The viscoelasticity of the Multi-Cone can be controlled by changing the amount of water it absorbs. Figure 2-3 shows the surface of the polishing media by observation using an optical microscope and scanning electron microscope (SEM). From this figure, it was observable that the polishing media expands after absorbing water. In addition, from the SEM observation, the presence of the core material was confirmed.

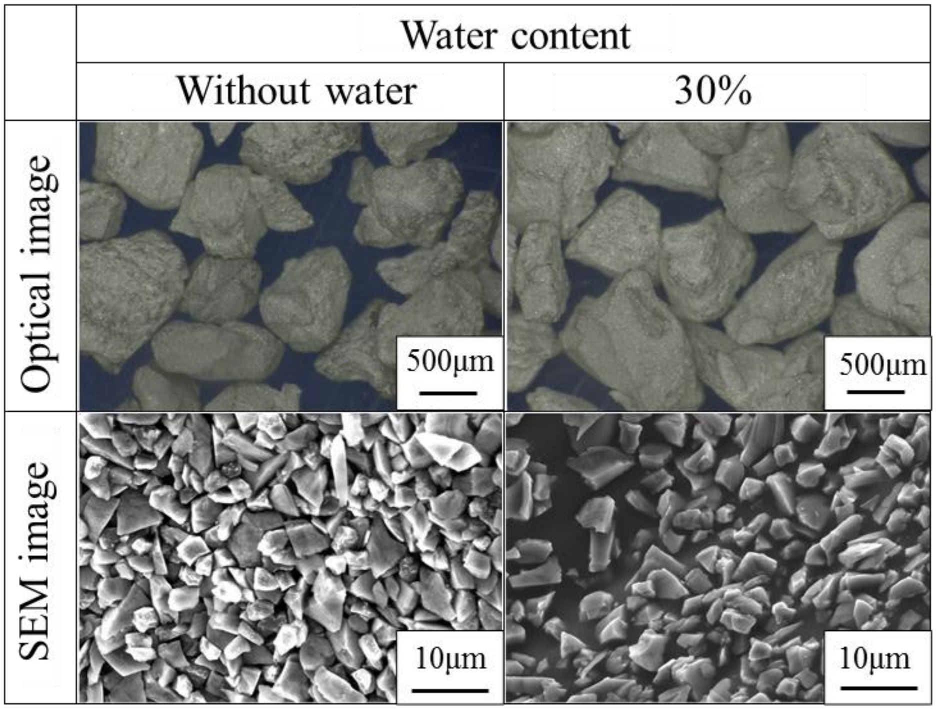


Figure 2-3 Surface observation of the polishing media before and after adding water.

2.2.2 <u>Method of adding water to the polishing media</u>

The polishing media mixing equipment used in this study is developed by OSG Co., Ltd, shown in Figure 2-4. The equipment is composed of the container and the water supplying unit. The container, rotating in clock wise at 48.3min^{-1} is responsible in mixing the multi-cone, multi-powder and water. The water supply unit with the compressed air of 2.5MPa, supplying the water thru the nozzle at a rate of 4cc/min. The mixing ratio of multi-con, multi-powder and water is shown in Table 2-2. The polishing media water content is depending on the experimental purposes. The combination ratio of 1000 g of Multi-cone, 30 g of Multi-powder, and 30% water content was the standard recommendation value issued by the developer for this polishing process.

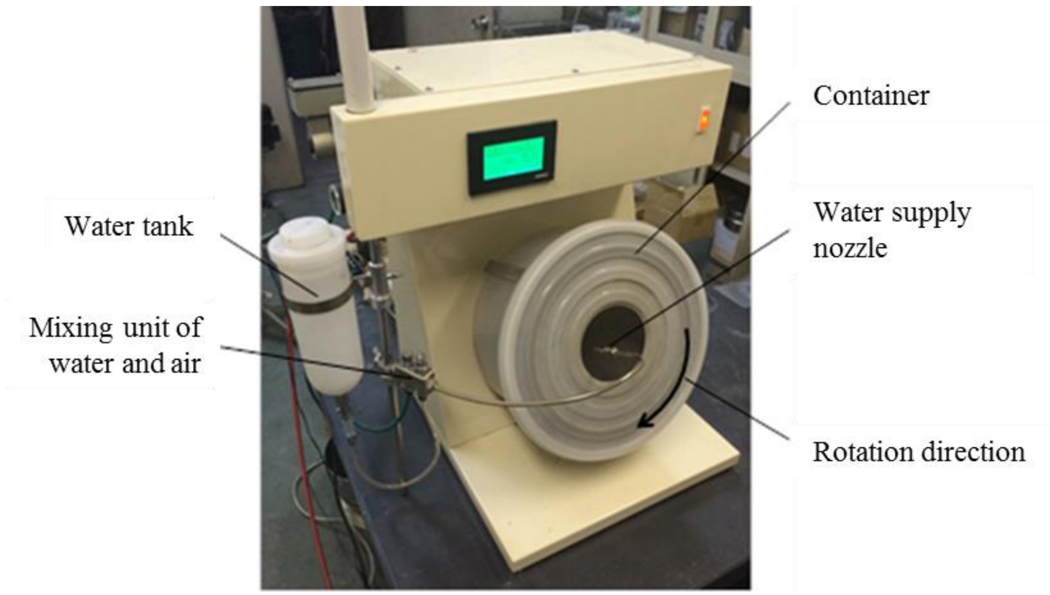


Figure 2-4 Polishing media mixing equipment.

Table 2-2 Mixing ratio of the polishing media.

Polishing media	Multi-Cone (g)	1000
	Multi-Powder #3000 (g)	30
	Water content (%)	10
		30
		50

2.2.3 <u>Method of measuring the mass of the polishing media</u>

The polishing media average mass per one grain was calculated by measuring the average mass of 150 randomly picked polishing media grain having a size of 0.5mm to 2.0mm. The device used for this measurement is the electronic balance GR2000 manufactured by A & D Co. Ltd.

2.2.4 <u>Method of measuring the polishing media modulus of elasticity</u>

The static modulus of elasticity of the polishing media measurements was performed by the compression test method using an autograph made by Shimadzu Corp., (EZ-SX 100N). A randomly selected single grain of polishing media of a size between 0.5 to 2.0 mm in diameter was placed on the stage as shown in Figure 2-5. Then, a compressive load was added by a cylindrical penetrator of 10 mm in diameter from the upper side of the polishing media. The compression test speed was 0.5 mm/min and the compression test ended when the test force reached 20 N. The polishing media modulus of elasticity was calculated by extracting the data from the start of polishing media deformation until the amount of deformation reaches 0.3 mm. The above experiment was repeated 10 times, and the average value of the modulus of elasticity was calculated.

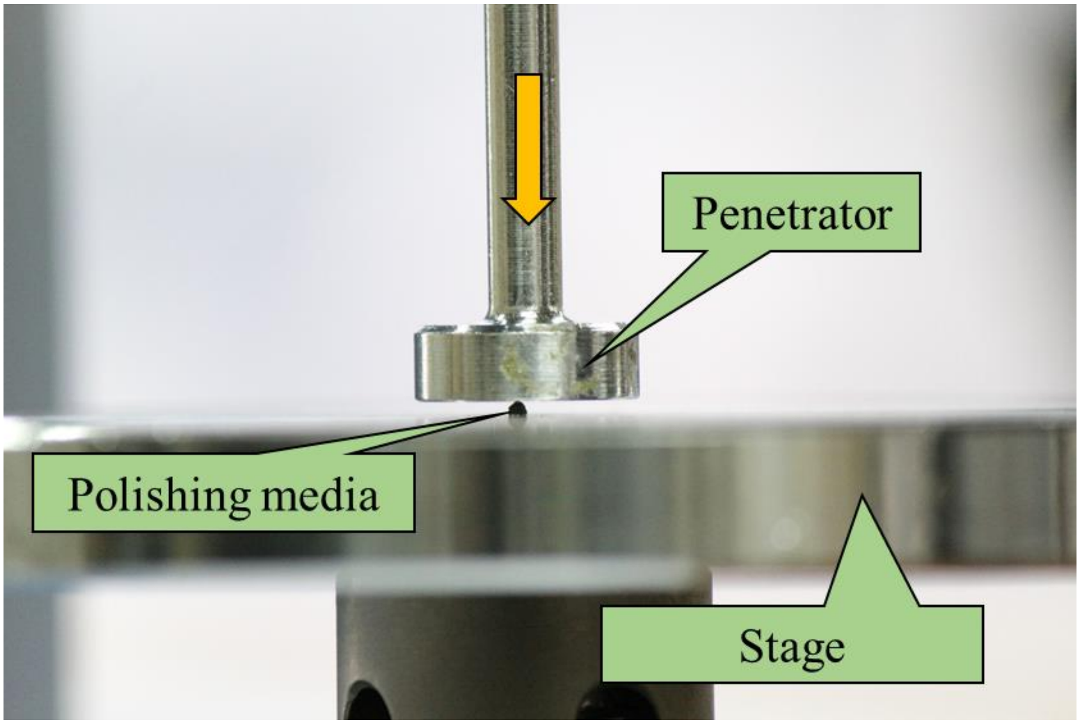


Figure 2-5 Photo of the compression test.

2.3. **Blast polishing experiment setup**

2.3.1 **Blast polishing machine**

Blast polishing machine used in this research is the Shot Machine A.one Polish (SMAP)-Type II developed by Toyo Kenmazai Kogyo Co., Ltd. A schematic diagram of the appearance and the internal mechanism of the device is shown in Figure 2-6. The polishing media is stored at the bottom part of this machine. During polishing process, the conveyer belt transported the polishing media towards the impeller. Then the rotating impeller by it centrifugal force injected the polishing media to work piece[21], [27]. The polishing media injection amount per unit time can be adjust using the flow pedal step value (five step of 1 to 5). The conveyer transport speed increase with the increase of pedal step value. In addition, the motor to rotate the impeller in connected with the inverter. The inverter value is adjustable using the inverter value button at the top of the machine (adjustable frequency: 6 to 20Hz). The polishing media injection speed is adjustable by controlling the rotation speed of the impeller using the inverter value button.

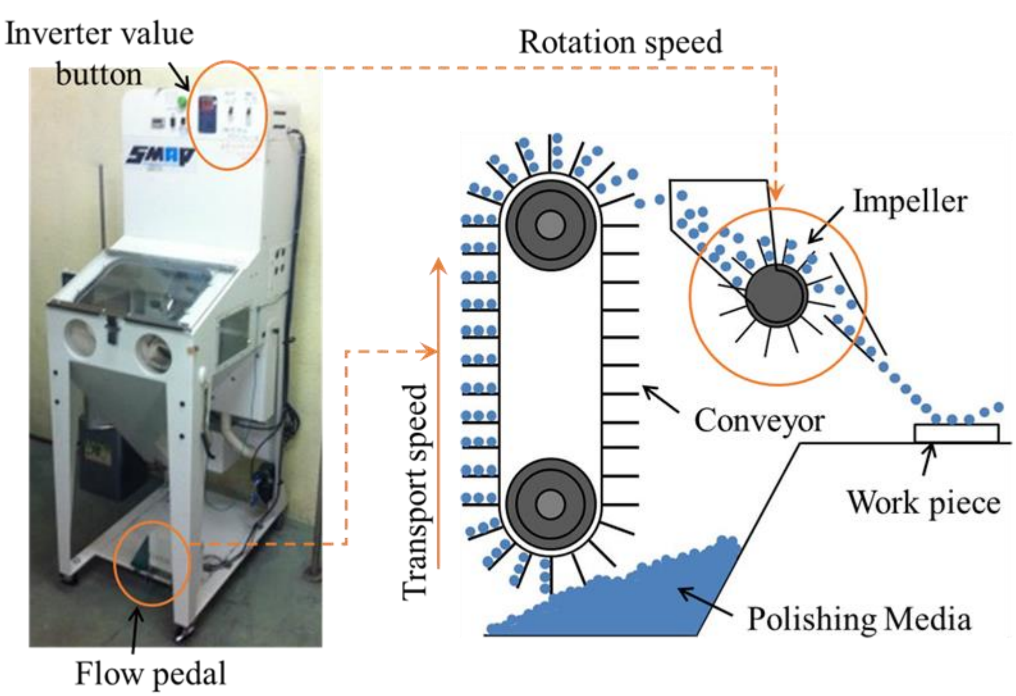
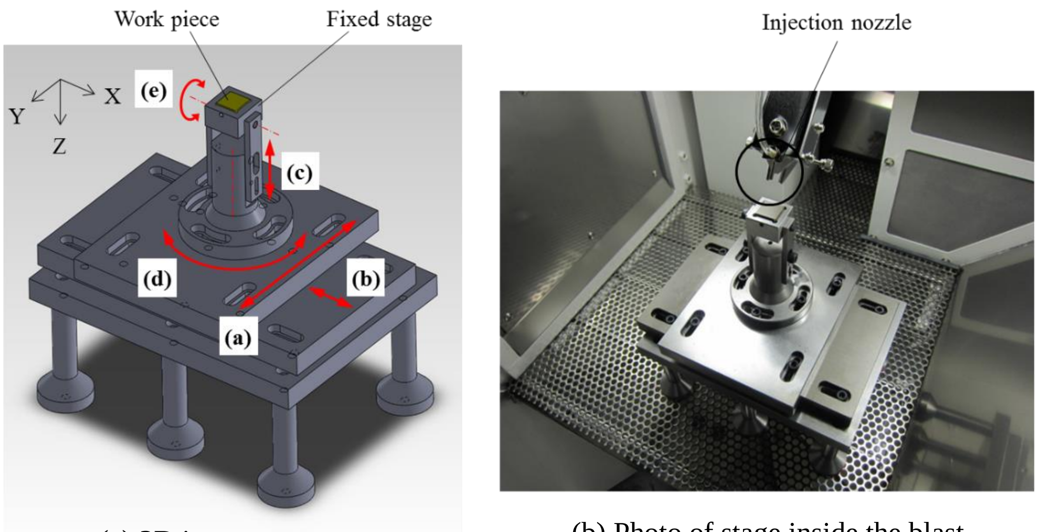


Figure 2-6 Detail of operating device on the blast polishing machine.

2.3.2 <u>Stage of the work piece</u>

Figure 2-7 shows the schematic diagram of the fix stage for the work piece. The work piece is place on top of the stage below the nozzle. The stage is can be adjustable in the direction as shown by the arrow. Front and back (in the figure (a)), left and right (in the figure (b)), and up and down movement in (in the figure (c)), the strut in the middle of the stage can also be rotated (in the figure (d), (e)). The stage is design so that it can be adjust to fulfill the needs of all the experimental condition.



(a) 3D image

(b) Photo of stage inside the blast polishing machine

Figure 2-7 3D image and photo of fixed stage for the work piece.

Figure 2-8 shows the positional relation between injection nozzle and the work piece. The distance between the work piece and the nozzle is changed by adjustment in the figure (a) and (c). The injection angle can be change by further adjustment in the figure (e). The nozzle width is also adjustable. The default nozzle width for this study is 5mm. The reason for this setting was to make sure that the width of the nozzle does not exceed the work piece size and also for the purpose to easily distinguished the polished area after the polishing process. The distance between the work piece and the injection nozzle (hereafter referred as injection distance), is set to a default injection distance of 20mm. The distance was set to that value by the evidence from the study about the impact of injection distance on machining efficiency[28]. So that the distance of the work piece and the injection nozzle is as close as possible and to make sure no interference occurs in the surrounding area between the work piece and the injection nozzle.

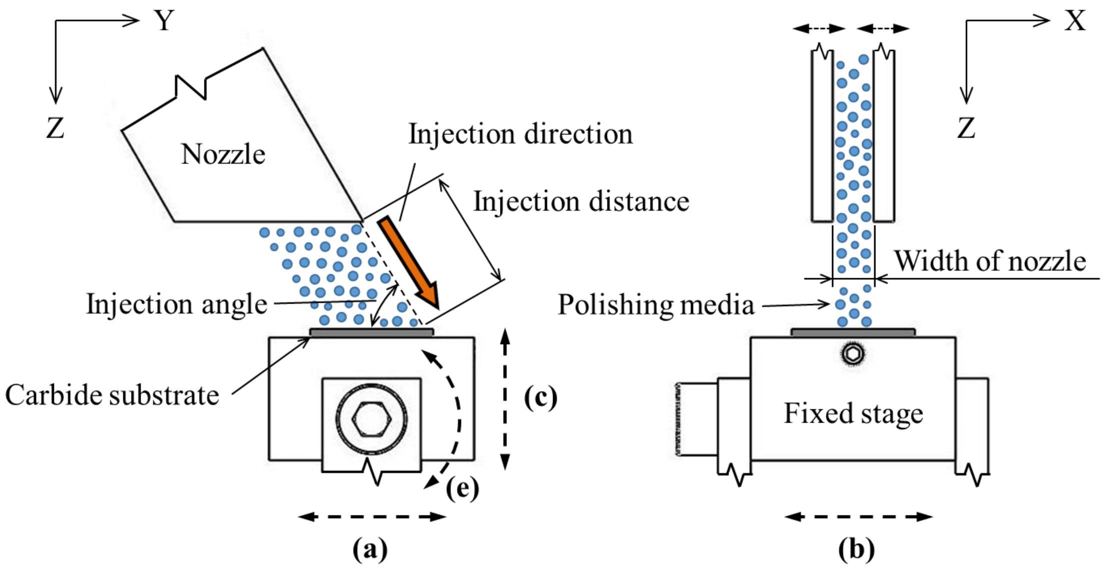


Figure 2-8 Positional relationship of nozzle and work piece.

2.4. Polishing media observation and injection speed measurement

2.4.1 Setup of high speed video camera

Figure 2-9 shows the schematic diagram of the high speed camera setup used to measure the polishing media injection speed. The polishing media was recorded perpendicular to the polishing direction using the high speed camera FASTCAM SA1.1 made by the Photoron Corporation. The shooting condition is as outlined in Table 2-3.

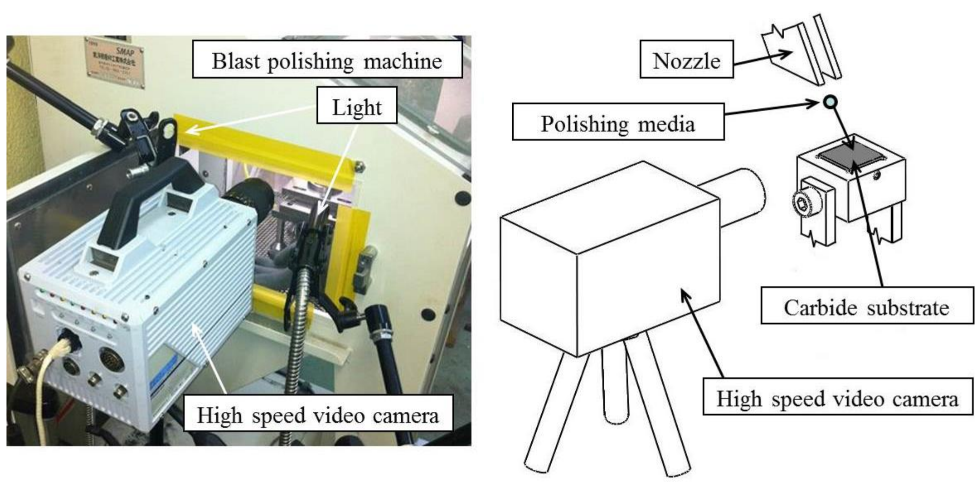


Figure 2-9 High speed camera setup to measure the polishing injection speed

Table 2-3 High speed camera setup to measure the polishing injection speed

Measurement of injection speed	Frame rate (frames/s)	50,000
	Frame size (pixel)	512×208
Deformation observation	Frame rate (frames/s)	250,000
	Frame size (pixel)	128×80

2.4.2 <u>Two-dimensional fluid analysis software</u>

The obtained footage by the high speed camera is then analyzed using two-dimensional (PTV：Particle Tracking Velocimetry) fluid analysis software, Dipp-flow developed by Kato Kouken Corporation. The software automatically identify each of the polishing media grain in the continuous video image. Then it track the movement of each grain and calculate the speed of each grain[29], [30]. The analysis condition is as shown in Table 2-4. The details of the method of measuring the projection speed measuring method and impact force of the polishing media in accordance with the present software is described in the next section.

Table 2-4 Analysis condition of PTV software

Measurement of injection speed	Analysis image number (frames)	400
	Interval of analysis image (μs)	20
	Scanning area (mm)	17×6
Deformation observation	Analysis image number (frames)	400
	Interval of analysis image (μs)	4
	Scanning area (mm)	3.5×2

2.4.2.1 <u>Polishing media injection speed measurement</u>

The measurement of the polishing media injection speed is conducted by selecting the polishing media that flew inside the PTV scanning area, shown in Figure 2-10. Ten samples is chosen. Then the injection speed of each sample is calculated. Finally the average injection speed of these 10 samples is calculated. The polishing media injection speed before the collision, v and after the collision, v' is calculated by using this method.

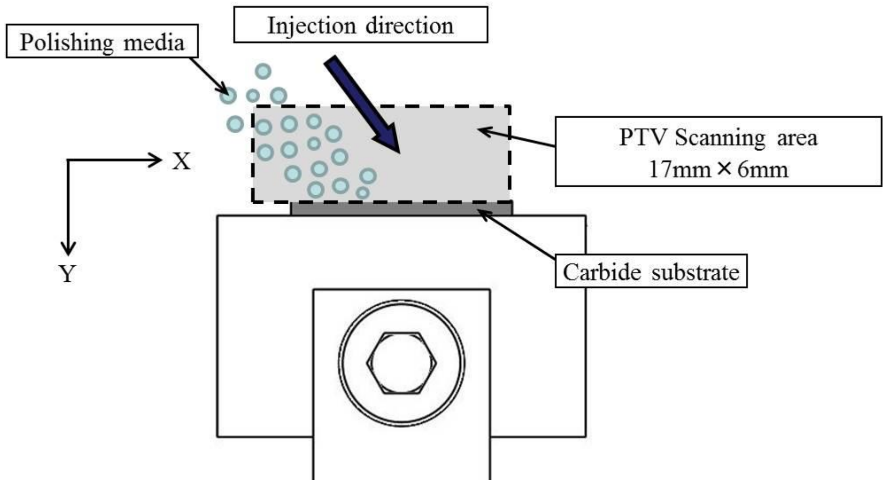


Figure 2-10 Schematic of scanning area on PTV software

2.4.2.2 <u>Measurement of the polishing media impact force to the work piece</u>

After the determination of the polishing media average injection speed before the collision, v and after the collision, v'. The impact force, F applied on the work piece surface during the collision is calculated using the Equation (1).

$$F = \frac{mv' - mv}{t} \qquad (1)$$

The time, t is the period of the collision which was determined from the captured video between the times the polishing media makes contact with the surface and immediately after it completely leaves the surface. The average mass, m per one grain polishing media in each water content condition was shown in Table 2-5. The polishing media average mass per one grain was calculated by the measurement method explained in the previous section, **section 2.2.3**.

Table 2-5 Polishing media average mass per grain.

Water content (%)	Average mass per grain (g)	Standard deviation (g)
10	0.513×10^{-3}	0.038×10^{-3}
30	0.673×10^{-3}	0.223×10^{-3}
50	0.953×10^{-3}	0.117×10^{-3}

2.4.2.3 Pressure distribution measurement method using a pressure sensitive film

Fig 2-11 shows the schematic diagram of the experiment in measuring the pressure distribution on the work piece surface by the impact of polishing media during the polishing process. The qualitative pressure sensing film used in this experiment is the Prescale MS type made by Fuji Film Co. This film can sense a range of pressure from 10 MPa to 50 MPa. The film turn to red color when under pressure of above 10 MPa and turn to darker red color under higher impact force. The maximum of pressure can be evaluated by distinguishing the red color darkness of the film. Since the film is pressure sensitive film, a protective film with a thickness of 0.5mm is placed on top of the film during the experiment. The experiment was conducted under polishing media injection time of 60s.

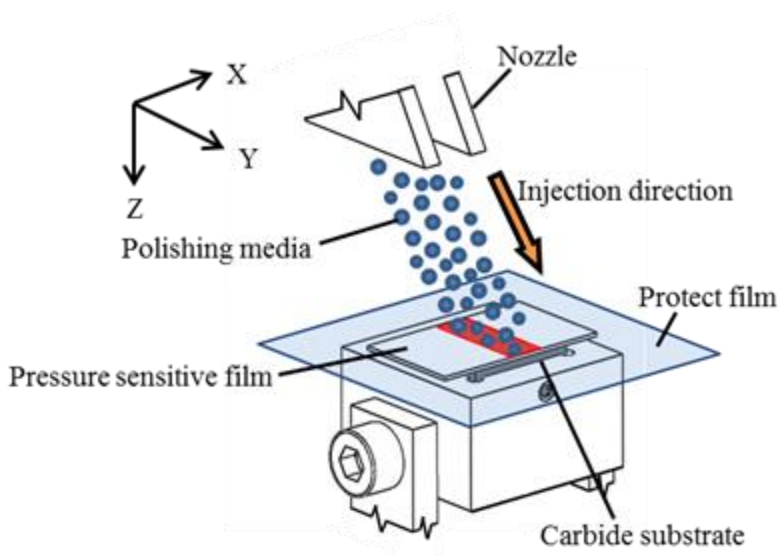


Figure 2-11 Schematic of experimental with pressure sensitive film

2.5. Cutting Test

2.5.1 Properties of drill

The cutting tools used for the drilling were 10.00 mm diameter uncoated carbide drills manufactured by OSG Corporation (NF-GDN10 type). A schematic representation of the drill and its geometry are shown in Figure 2-12. The base material of the drill is cemented carbide. The drill consists of two flutes surface with helix angle of 20° and point angle of 130°. The overall length of the drill is 109 mm with its flute length of 65 mm.

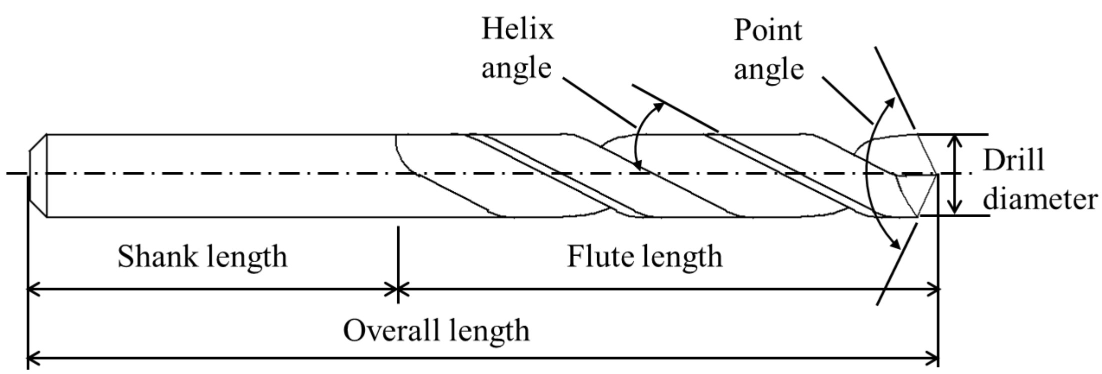


Figure 2-12 Schematic of NF-GDN10 drill

2.5.2 Polishing condition of the flute surface

The schematic of the polishing treatment by the blast polishing are shown in Figure 2-13. This figure shows the position relation of nozzle and drill under polishing angle of 45 degree. The polishing angle can be adjust by inclining the drill. The polishing distance is set to 20 mm[28]. In order to protect the cutting edge of the tool, the polishing process is carried out by moving while rotating the tool starting from the shank side to the cutting edge direction of the tool. The polishing treatment is performed by changing the polishing time and polishing media water content while the polishing media injection speed is set to constant value.

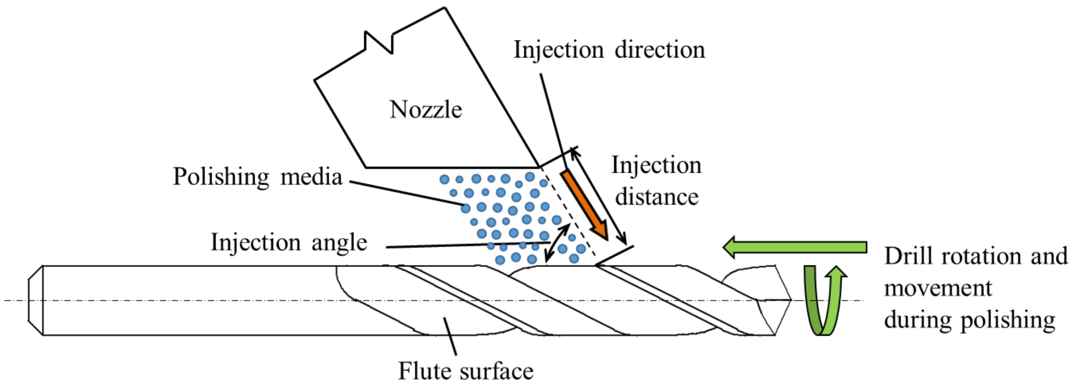


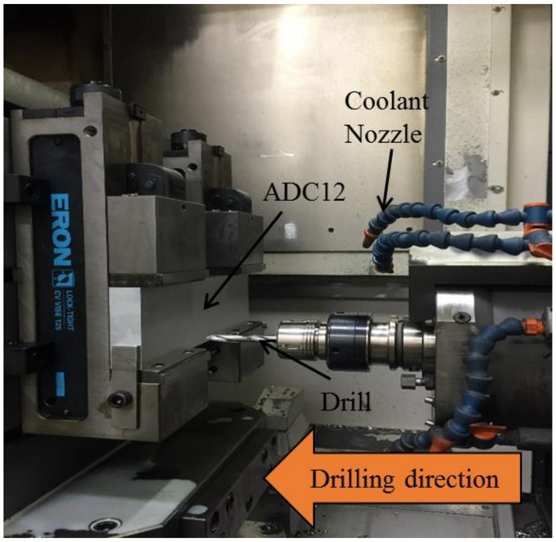
Figure 2-13 Schematic of blast polishing treatment to the drill flute surface.

2.6. Cutting Test Machine

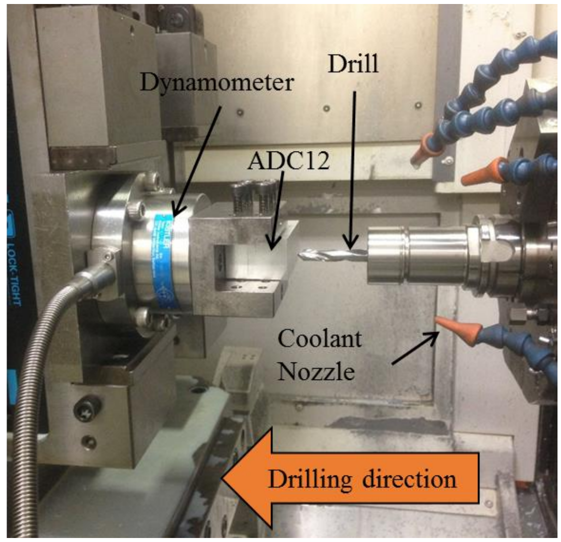
The cutting test is performed using the computer numerically controlled (CNC) machine, MB-5000HA manufactured by Okuma Corporation. Details of the cutting machine are shown in Table 2-6. The test was conducted in horizontal direction under flooded condition, as shown in Figure 2-14. The work piece used in this cutting test is aluminum alloy, ADC12. The cutting test machine is equipped with an external coolant system. The cutting test are repeated two times for each drill condition to ensure that the experimental results are repeatable. The most representative experimental data were selected for presentation in this paper. The measurement method of the cutting force is described in the next section.

2.6.1 Cutting force measurement method

The cutting resistance measurement is conducted by using dynamometer sensor, Type 9272, amplifier: Type 5015 developed by Kistler Instrument Corporation which was mounted between the jig and the work piece as shown in Figure 2-14 (b). Each drilling cycle requires approximately 5s duration between the initial contact and the complete retraction of the drill bit. The average cutting force is calculated from the difference in thrust between the onsets of chip clogging to the retraction of the drill, as depicted in Figure 2-15.



(a) Cutting test setup without cutting resistance measurement test



(b) Cutting test setup for measuring the cutting force.

Figure 2-14 Experimental setup of the cutting test

Table 2-6 Specification of cutting machine.

Machine name	MB-5000H
Electric motor	Main shaft: AC 26 (kW)/ 18.5 (kW)
	Feed shaft: X 4.6 (kW), Y, Z 3.5 (kW)
Main shaft	Rotation speed: 50 – 15000 (rpm)
	Taper socket: No. 40
Size (mm)	Width: 2420
	Length: 4700
	Height: 2647

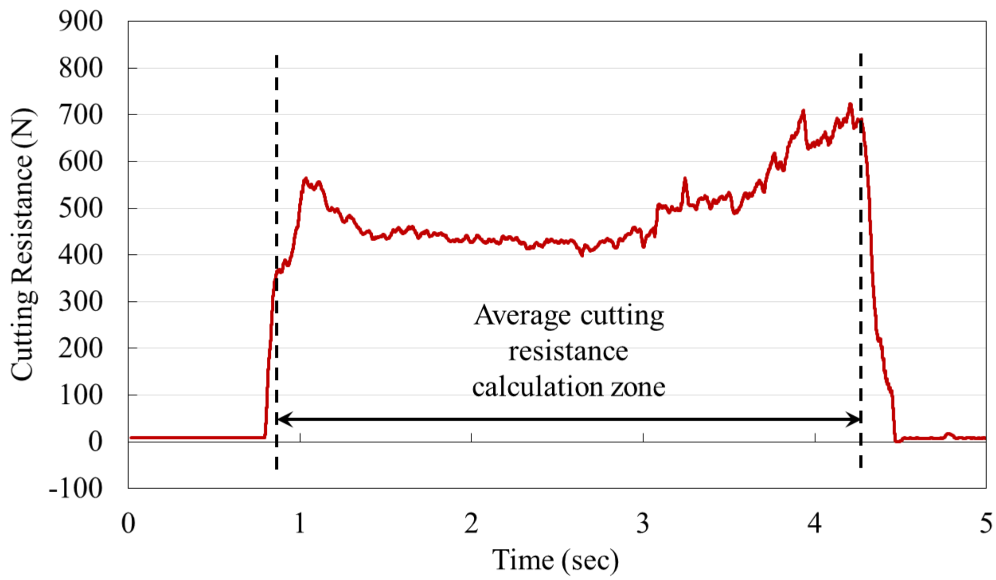


Figure 2-15 Cutting resistance line graph and the average cutting force calculation zone

2.7. <u>Friction Test</u>

2.7.1 <u>Friction test machine</u>

The friction test were carried out to examine the influence of the grinding mark on the tool surface to the adhesion behavior of the aluminum alloy, ADC12. The test is carried out in two conditions which is the dry condition and wet (under lubricant) condition. The experiment under dry condition is conduction using the FPR-2100 device made by Rhesca Co., Ltd and the device use for wet condition is the HEIDON type14: FW made by Shinto Scientific Co., Ltd.

Figure 2-16 shows the schematic diagram of the friction test in each of the condition. The lubricant oil used under wet condition is the same type of lubricant oil used in the cutting test. For the test method, as to replicate the situation of the chip discharged on the cutting tool surface during cutting test as near as possible, the friction test is set to linear reciprocating direction. In dry conditions, the friction coefficient is measured by the frictional force resistance sensor that determined the resistance force between vertical load and the surface during round trip test. As for the wet condition, the friction coefficient is determined by friction resistance send by load transducer upon receiving the signal of the vertical load resistance force from the adapter.

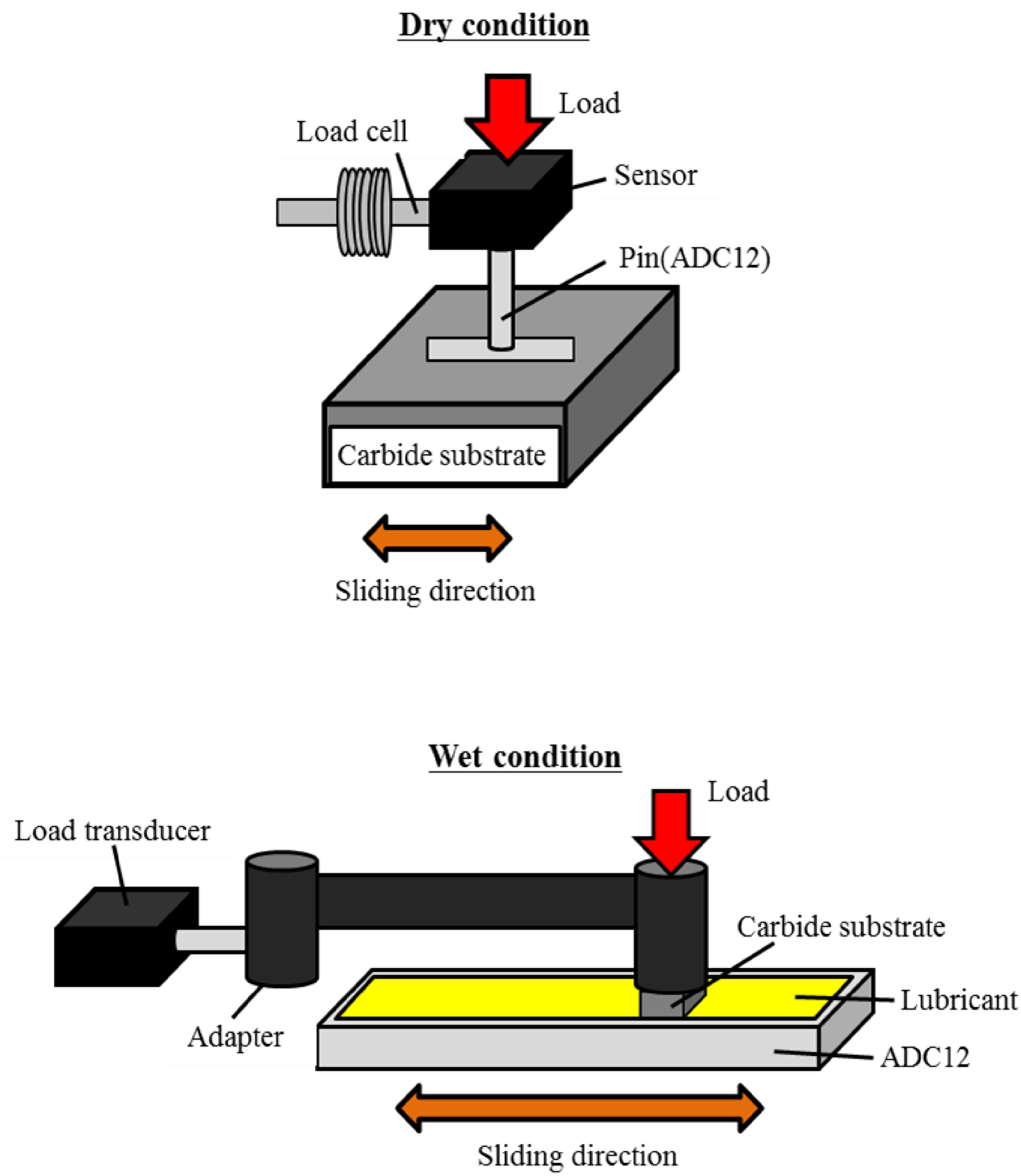
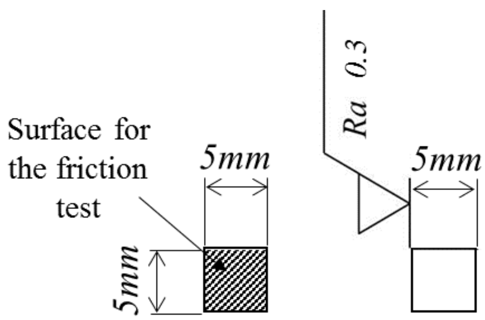


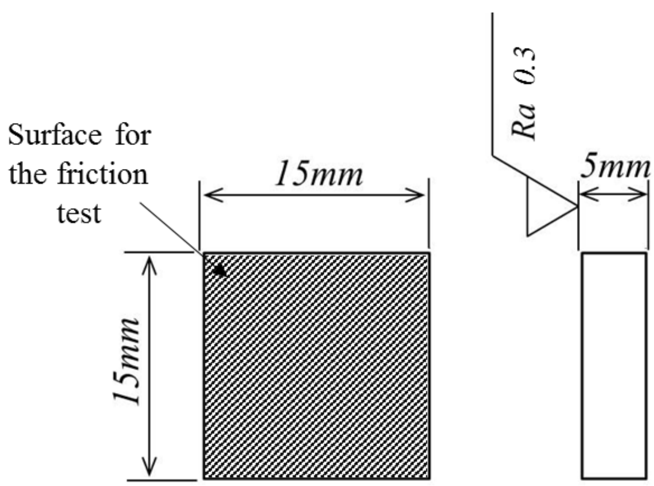
Figure 2-16 Schematic of friction test (Dry condition and Wet condition)

2.7.2 <u>Pretreatment method of carbide substrate surface before the friction test</u>

Figure 2-17 shows the geometry of the cemented carbide use as the specimen in the friction test. Since the test is conducted to investigate the influence of grinding mark on the surface to the adhesion behavior of ADC12, the specimen test surface need to pretreated to impart the grinding mark on its surface. The surface grinding machine: SGM-52 manufactured by Nagase Integrex Ltd., is used for this purpose. The surface roughness, Ra after the pretreatment is about 0.3μm.



(a) Friction test under dry condition



(b) Friction test under wet condition

Figure 2-17 Carbide substrate geometry under each friction test condition

2.7.3 <u>Measurement method of mass of the adhered aluminum</u>

The amount of adhesion of the aluminum alloy on the cemented carbide surface is measured by calculating the different of the weight of the carbide substrate before and after the friction test. The device used for this measurement is the electronic balance GR200 made by A & D Co. Ltd. This measurement is performed three time per condition to get the average value of the mass of adhered aluminum on the surface.

2.8. <u>Surface Evaluation Devices and Evaluation Method</u>

2.8.1 <u>Laser microscope</u>

The measurement of surface roughness and the observation of the work surface is conducted by using the laser microscope LEXT OLS3100 manufactured by Olympus Corporation. This laser microscope is capable of observing in detail to valley and bottom of the surface and can finely observed the changes in irregularities present on the surface. The details of the profile measurement and surface roughness measurements methods are shown in the next section.

2.8.1.1 <u>Work surface observation and measurement method</u>

The observation and the measurement of the surface roughness of the surface is conducted by using 50x lens. This device performed the measurement by collecting the three-dimensional data of the area of 250μm × 180μm. This process is repeated three times to get the average surface roughness of the process surface. The observation region is conducted at the deepest portion in the polishing region since the deepest portion shows the lowest surface roughness value as it has been confirmed by the previous study[31].

2.8.1.2 <u>Surface profile fixed point observation method</u>

Figure 2-18 shows the measurement area of the surface morphology transition. The position of observation was along the AB line, in the center of the laser microscope measurement area. The direction of measurement was along the injection direction of the polishing media as shown by an arrow in the figure. To ensure the precise measurement along the AB line, a fixture was installed on the laser microscope stage and the work piece was placed on this fixture in each measurement procedure.

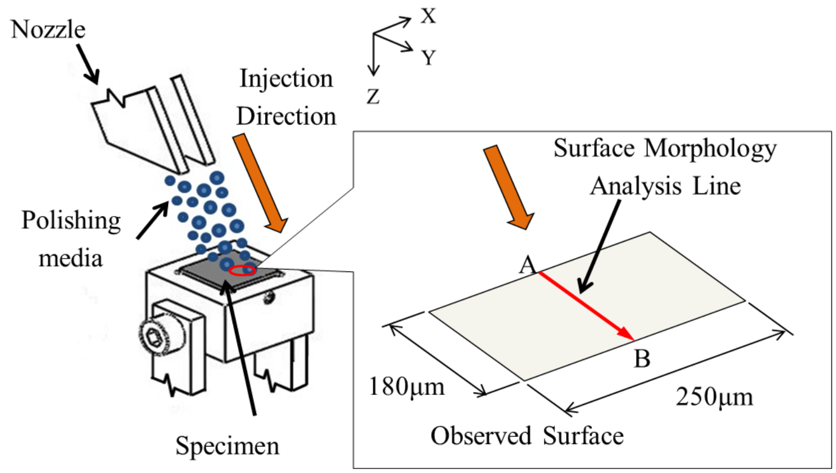


Figure 2-18 Measurement of the polished surface morphology by laser microscope

2.8.2 Atomic force microscope (AFM)

The surface topography in 3D and surface profile measurement of the grinding mark on the cutting tool flute surface was conducted using atomic force microscope (AFM), SPM-9500J3 developed by Shimadzu Corporation.

2.8.3 Scanning electron microscope (SEM)

Since laser microscope is limited in observing the work surface in micro-scale, the surface observation was also conducted by using Scanning Electron Microscope (which will be mention afterwards as SEM) JSM-6390TY, manufactured by JOEL Co., Ltd.

2.8.4 Surface hardness measuring method

The surface hardness measurement was conducted by using a Micro-Vickers hardness tester made by Shimadzu Corp., (HMV-1). The hardness measurement condition was established under a compression load of 4.9 N with an indentation time of 30 seconds. This measurement was repeated 10 times and then the average hardness was calculated.

3. Effect of various factors in blast polishing process on the surface condition of cemented carbide substrate

3.1. Introduction

In this chapter a studies is conducted by investigating the relationship of the factors related in the polishing process to the polished surface condition. For this purpose the polishing parameters such as the polishing time, injection speed, injection angle as well as the effect of water content inside the polishing media is investigated.

In the previous studies conducted by Kitajima et al.[18]–[20], reveals the influence of polishing media injection speed to the surface roughness of the process surface. However those studies only reveals the influence of polishing media under constant injection speed. The influences of varying the polishing media injection speed to the surface condition of the process surface has not yet been clarified. Therefore, in this chapter, the investigation of the relation between surface roughness and polishing time when changing the injection speed and it effect on the work surface condition by observing the process surface after each polishing process is conducted.

In addition, the influence of polishing media injection angle on the process surface under maximum injection speed were also investigated. This is because the kinetic energy of the polishing media is thought to have the significant impact on processing the work surface in this blast polishing process. Therefore, the purpose of this study is also to understand on the vector force distribution and polishing behavior under different injection angle conditions.

Finally the relation of polishing media water content to its mass and kinetic energy is investigated by varying the amount of water the polishing media absorbs. Additionally, an experiment is conducted to study the influence of mass of the polishing media on the process surface condition by injected the polishing media with different water content conditions at the maximum injection speed.

3.2. Experimental and Evaluation Method

3.2.1 Study on the influence of polishing media injection speed

In this section the experiment were carried out under the injection conditions as shown in Table 3-1. The polishing media water content used in this experiment is set to 30%. . The combination ratio of 1000 g of Multi-cone, 30 g of Multi-powder, and 30% water content was the standard recommendation value issued by the developer for this polishing process. The injection direction was set to 20 mm in all injection speed conditions. This distance was set so that the work piece and the injection nozzle distance was as close as possible and to make sure that no interference occurs in the surrounding area between the work piece and the injection nozzle.

For the study to examine the surface morphology transitions of the work surface after each polishing time, the fix point observation is conducted before the polishing and up until 270 seconds of polishing process, where at this polishing period, the surface morphology almost in all injection speed conditions has flatten.

Table 3-1 Injection condition for researching the relationship of polishing time and surface roughness in several injection speeds.

Injection condition	Injection speed (m/s)	12.3 - 59.5
	Polishing time (s)	0 - 510
	Injection quantity (g/s)	36
	Injection angle (deg.)	45
	Width of Nozzle (mm)	5
	Injection distance (mm)	20
Polishing media	Multi-Cone (g)	1000
	Multi-Powder #3000 (g)	30
	Water content (%)	30

3.2.2 Study on the influence of polishing media injection angle

Table 3-2 shows the experimental setup in investigating the relationship of polishing time and surface roughness in different injection angles conditions. The injection angle of 15 degree, 45 degree, 75 degree, and 90 degree is investigated in this experiment by changing the inclination of the stage that hold the carbide substrate to its fix position. The inclination conditions of the stage is as shown in Figure 3-1. The injection direction was set to 20 mm in all injection angles condition. In this study the polishing media water content is set to 30%. The injection speed of 59.5 m/s is used in this experiment which is the maximum injection speed obtained by this polishing machine. The polishing process is conducted until 270 seconds.

In order to examine the surface profile transition of the work surface after each polishing time, the fix point observation is conducted before the polishing process up until 270 seconds.

Table 3-2 Injection condition for researching the relationship of polishing time and surface roughness in several injection angles.

Injection condition	Injection speed (m/s)	59.5
	Polishing time (s)	0 - 270
	Injection quantity (g/s)	36
	Injection angle (deg.)	15, 45, 75, 90
	Width of Nozzle (mm)	5
	Injection distance (mm)	20
Polishing media	Multi-Cone (g)	1000
	Multi-Powder #3000 (g)	30
	Water content (%)	30

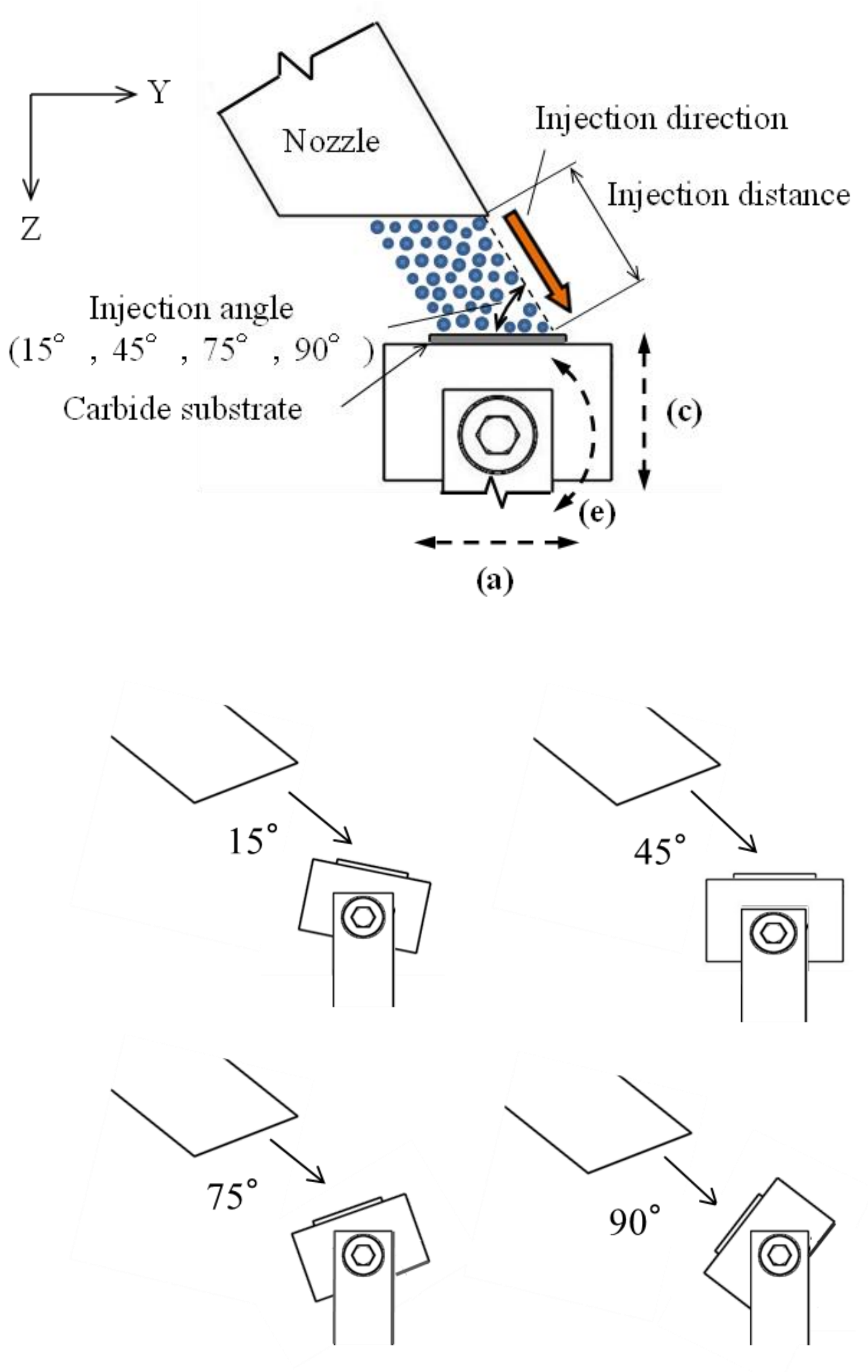


Figure 3-1 Positional relationship between the fixed stage and the nozzle at the time of changing the injection angle.

3.2.3 Study on the influence of polishing media water content

Table 3-3 shows the experimental setup in investigating the relation of polishing time and surface roughness under several water content conditions. In this experiment the influence of water content of 10%, 30% and 50% is investigated. The injection speed of the polishing media in each water content conditions is set to maximum injection speed conditions which is the 59.5 m/s. The polishing time is up until 510 seconds, which is set in order to compare with the results in the experiment of investigating the influence of injection speed to the surface roughness when the water content is constant, 30% water content condition.

Table 3-3 Injection condition for researching the relationship of polishing time and surface roughness in several water content rate.

Injection condition	Injection speed (m/s)	59.5
	Polishing time (s)	0 - 510
	Injection quantity (g/s)	36
	Injection angle (deg.)	45
	Width of Nozzle (mm)	5
	Injection distance (mm)	20
Polishing media	Multi-Cone (g)	1000
	Multi-Powder #3000 (g)	30
	Water content (%)	10
		30
		50

3.3. **Result and Discussion**

3.3.1 **Influence of polishing media injection speed on the process surface**

3.3.1.1 **Surface roughness and injection speed relation**

Figure 3-2 shows the relationship of the polishing media injection speed and the polishing time when the polishing media water content was 30% with an injection angle of 45 degrees. From this figure, when the injection speed was 12.3 m/s, the surface roughness value declines very slowly. However, when under the injection speed of 31.5 m/s or higher, the surface roughness value shows a sharp decline shortly after the start of polishing. Finally, after a certain polishing time, the surface roughness saturates. It was observed that as the injection speed was increased, the time for the surface roughness value to saturate becomes shorter and the surface roughness was found to saturated lower. From these results, the injection speed of the polishing media was proven to be one of the factors that influence this process, where high injection speed greatly improves polishing efficiency.

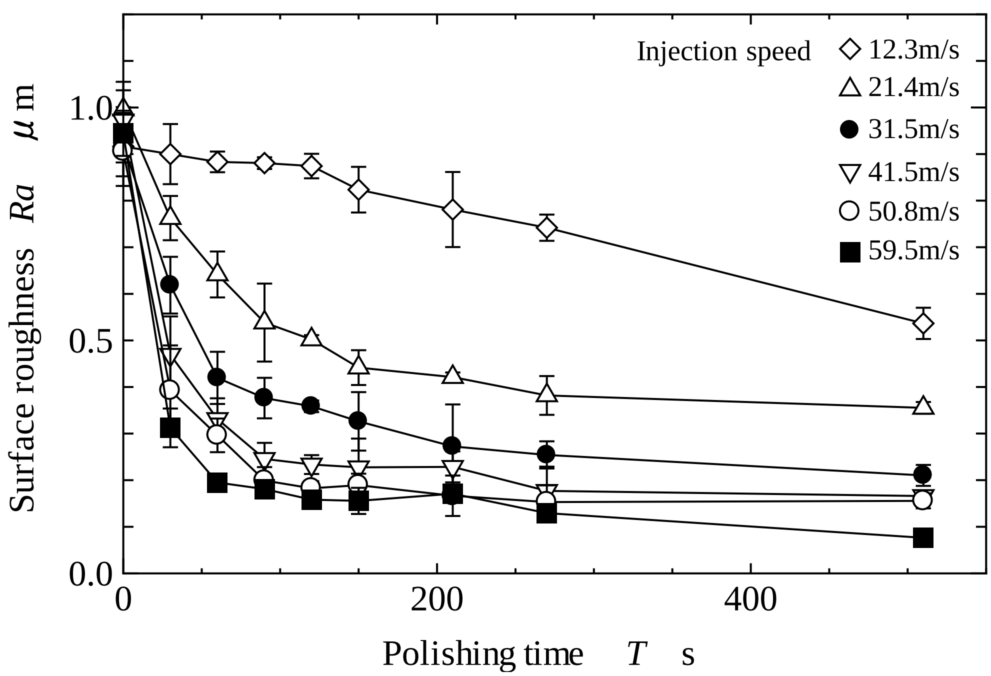


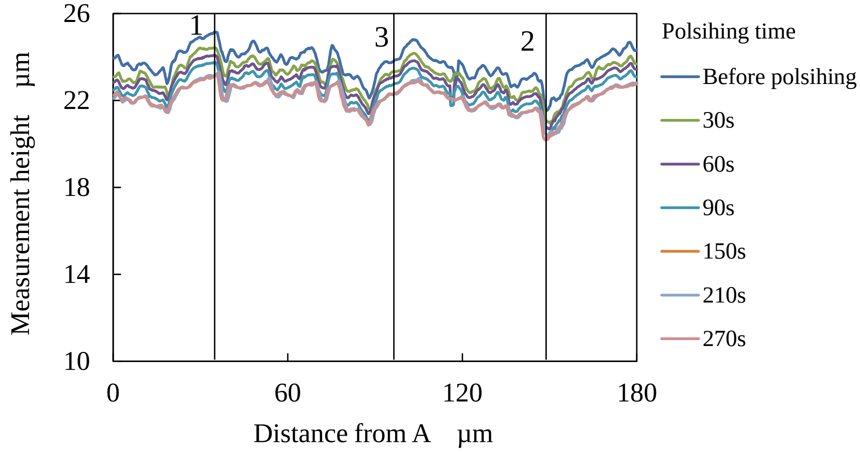
Figure 3-2 Relation of polishing time and surface roughness in each injection speed under water content 30% and injection angle 45 degree.

3.3.1.2 Observation of surface morphology transition

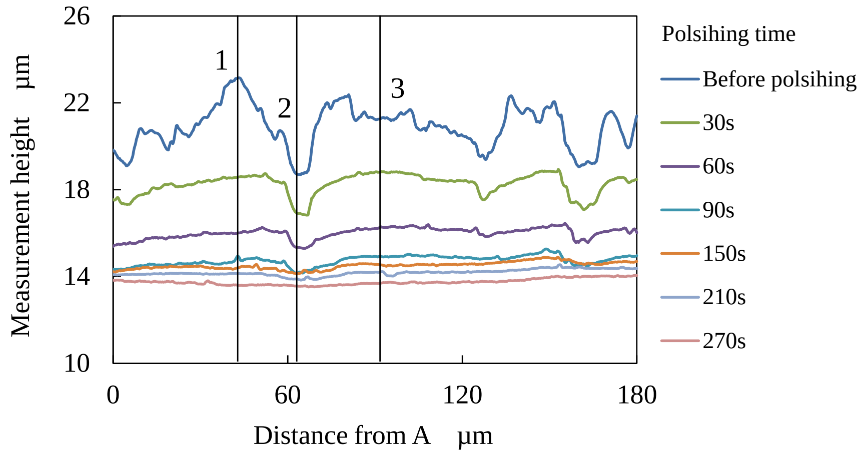
Figure 3-3 (a), (b), and (c) show the fixed-point observation of the polished surface morphology transition under injection angle 45 degrees. From Figure 3-3 (a), when the polishing media injection speed was 12.3 m/s, the polishing process shows little progress. On the other hand, from Figure 3-3 (b) and (c), when the injection speed was 31.5 m/s and higher, the polishing progress was observed clearly where the surface gradually flattens along with an increase of polishing time, particularly under an injection speed of 59.5 m/s.

The polishing removal depth per unit of time (hereafter referred as the polishing rate) was also measured in three positions as shown in the vertical line with the circled numbers in Figure 3-3 (a), (b), and (c) in order to understand the polishing behavior in each position. Position 1 in the figure refers to the highest peak of carbide surface morphology before the polishing process, while position 2 refers to its lowest valley and position 3 refers to the relatively flat plain surface. The result of this measurement was shown in Figure 3-4 (a), (b), and (c). From this result, it was clear that in all of the injection speed conditions, the highest polishing rate was achieved within 30 seconds of the polishing process. In addition, the polishing rate of position 1 (peak) was the highest, followed by position 3 (flat), and finally position 2 (valley). The polishing rate of position 2 (valley) was about 75% that of position 3 (flat) at the 30 seconds polishing time zone, refer Figure 3-4 (c). Thus, the valley was also polished at a relatively high rate, indicating that the abrasive grains also reached the valley.

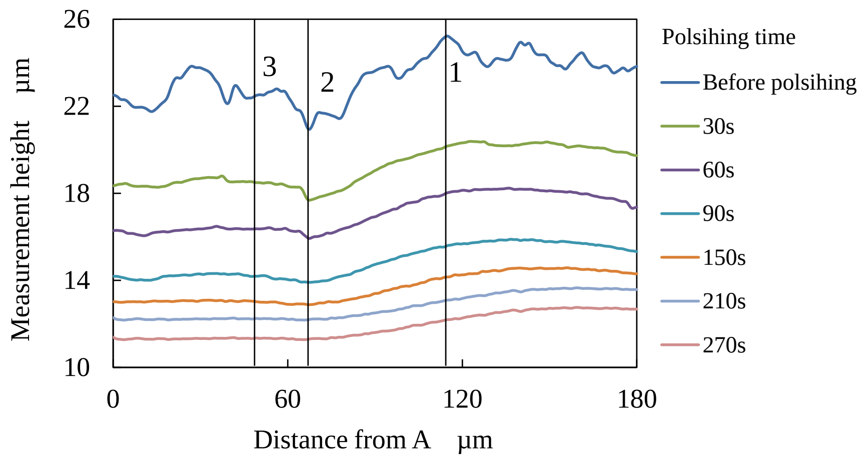
Figure 3-5 shows the schematic of when the polishing media collides with the carbide surface. The polishing media as shown in the figure has a viscoelastic body with a thick abrasive grain layer on its surface. During the collision, the polishing media at first collided on the peak position of the surface morphology. Then, due to the core material viscoelasticity, the polishing media deformed and reach the valley of the surface. Hence, a sufficient bite force was also applied by the abrasive grain when processing the valley part of the surface.



(a) Injection speed 12.3m/s

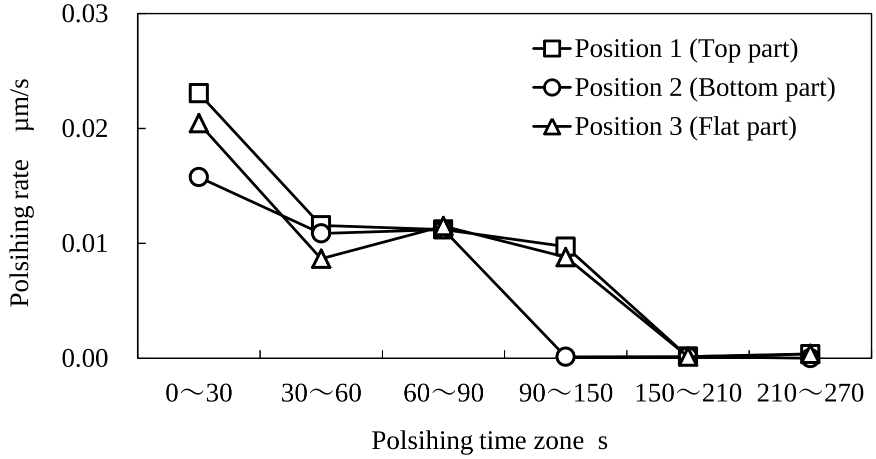


(b) Injection speed 31.5m/s

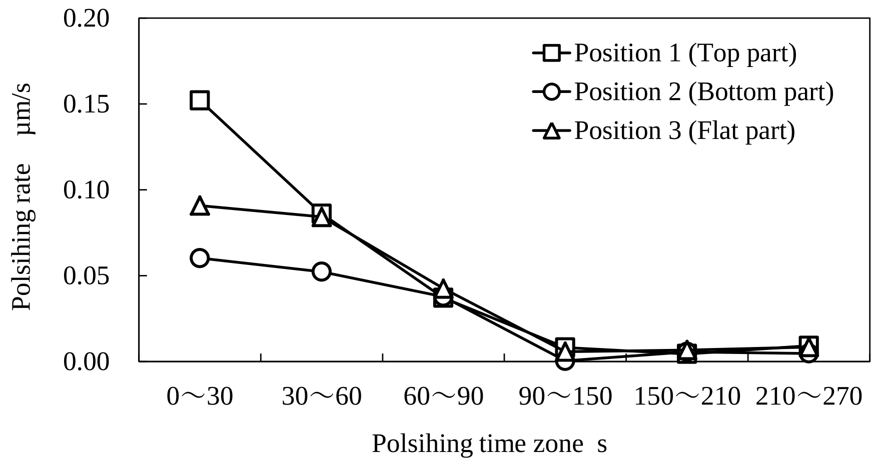


(c) Injection speed 59.5m/s

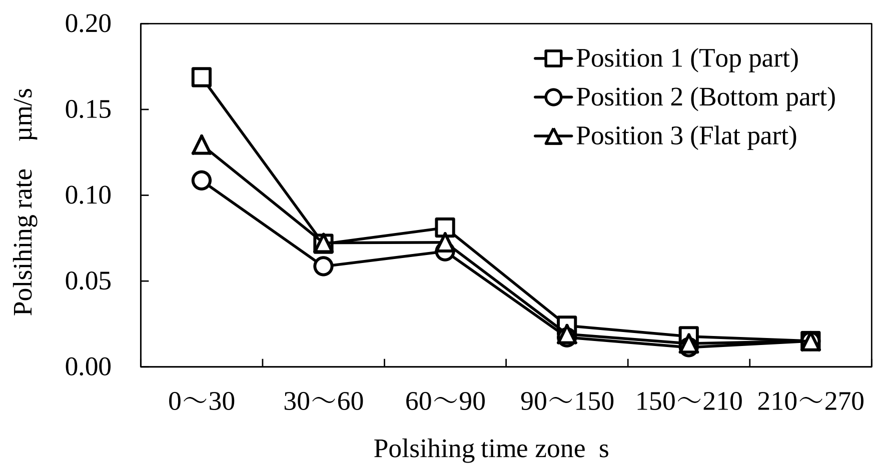
Figure 3-3 Profile shape of the polished surface in each injection speed



(a) Injection speed 12.3m/s



(b) Injection speed 31.5m/s



(c) Injection speed 59.5m/s

Figure 3-4 Polishing rate of each polished position in each injection speed.

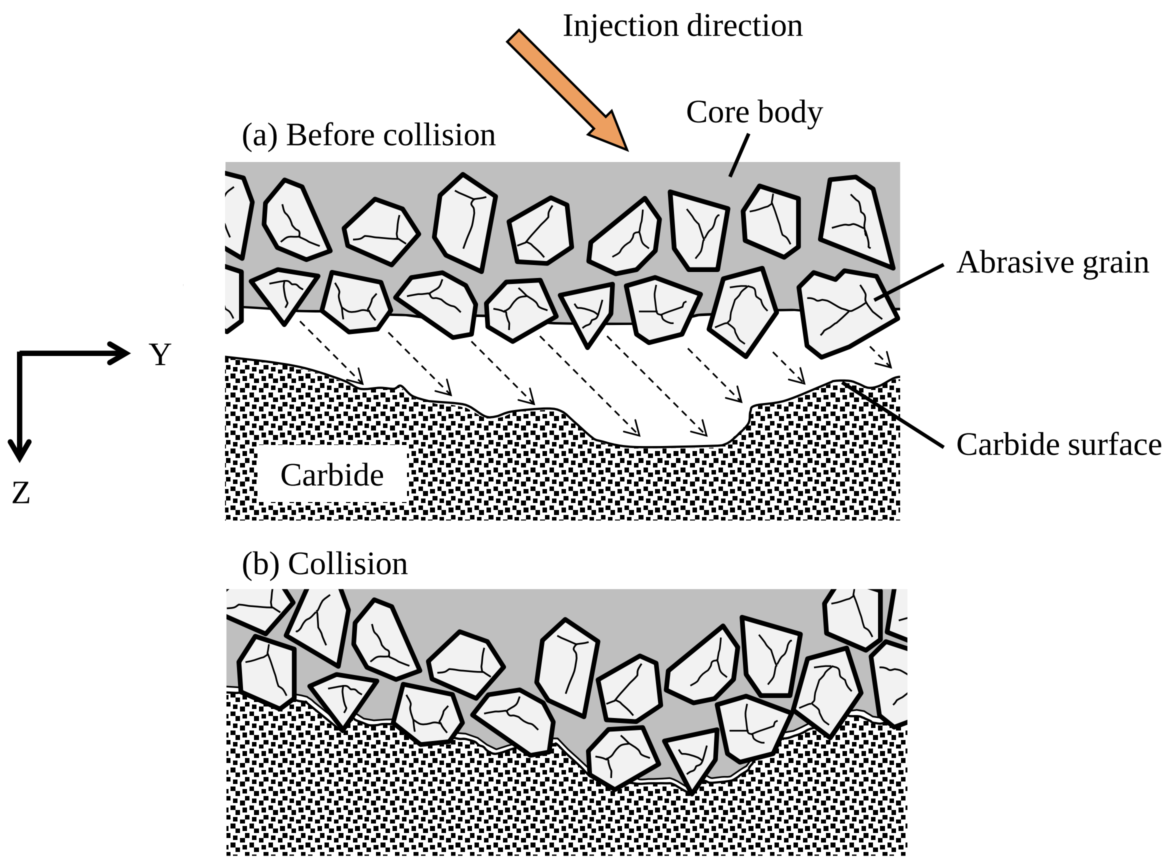


Figure 3-5 Schematic of when the polishing media collides with the carbide surface.

3.3.2 Influence of polishing media injection angle on the process surface

3.3.2.1 Surface roughness and injection angle relation

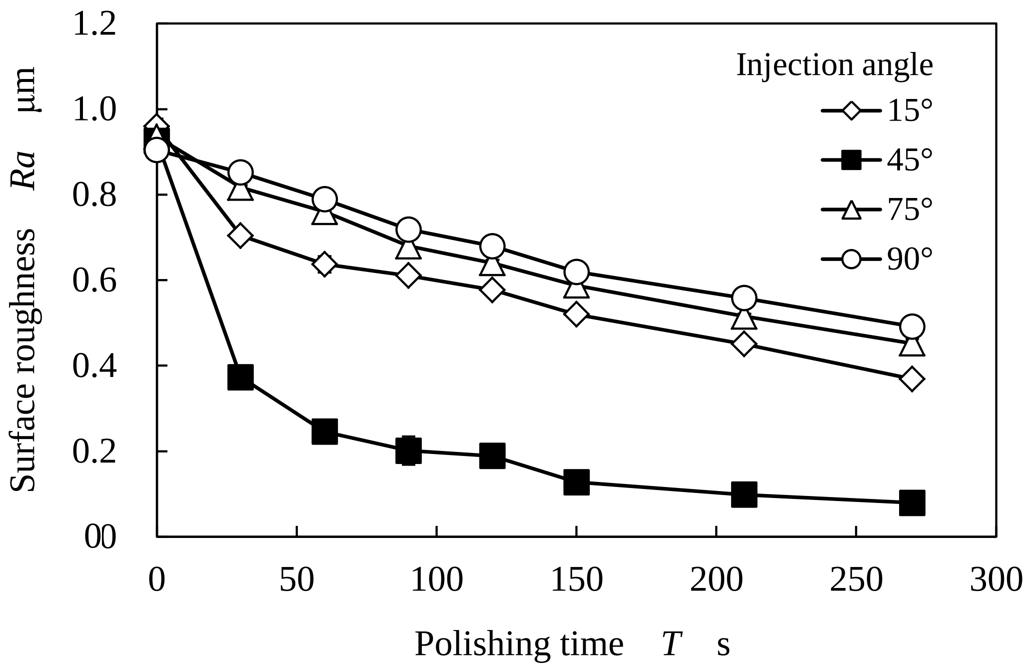
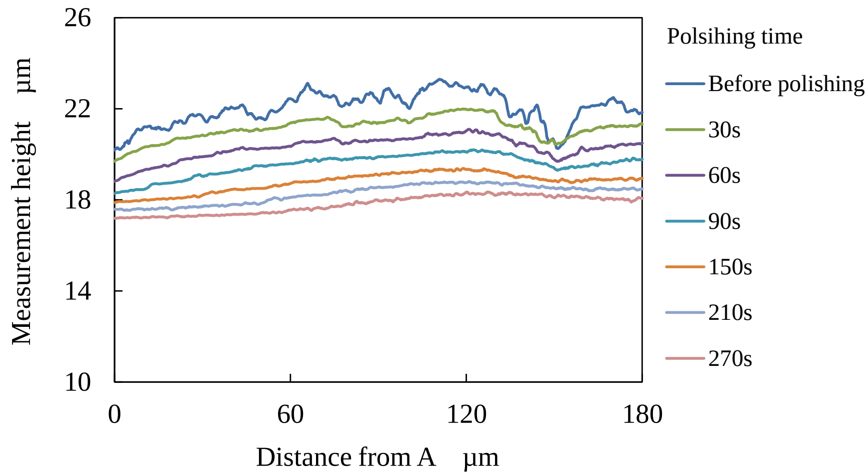


Figure 3-6 Relation of polishing time and surface roughness in each injection angle under water content 30% and injection speed 59.5 m/s.

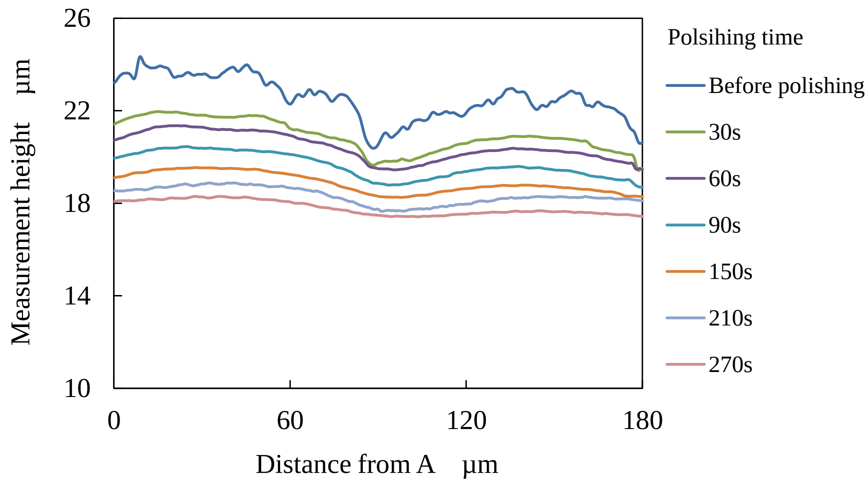
Figure 3-6 shows the relationship of the polishing time and the surface roughness in each injection angles conditions where the polishing media water content was 30% and the injection speed was 59.5 m/s. From this figure, injection angle 45 degrees has highest surface roughness declining rate, then followed by other injection angle in the order of 15 degrees, 75 degrees and finally 90 degrees. Furthermore, when comparing the injection angle 15 degrees and 75 degrees, injection angle 15 degrees declining rate is greater. In the case in injection angle 90 degrees condition, even though at the highest injection speed condition, the surface roughness declining rate is very low. This observation dictated the significance of vector forces under each injection angle conditions. The vector force was separated into the horizontal component force (the removal force that flattens the surface which influences the surface roughness decline rate) and the vertical component force (the bite force that bite the surface which influence the surface removal rate and further explained in **section 3.3.2.2**). Hence, compared to an injection angle of 45 degrees, the horizontal component force under an injection angle of 90 degrees was theoretically absent. Therefore, the surface roughness value decreases slowly along with an increase in polishing time.

3.3.2.2 Observation of the polished surface morphology transition

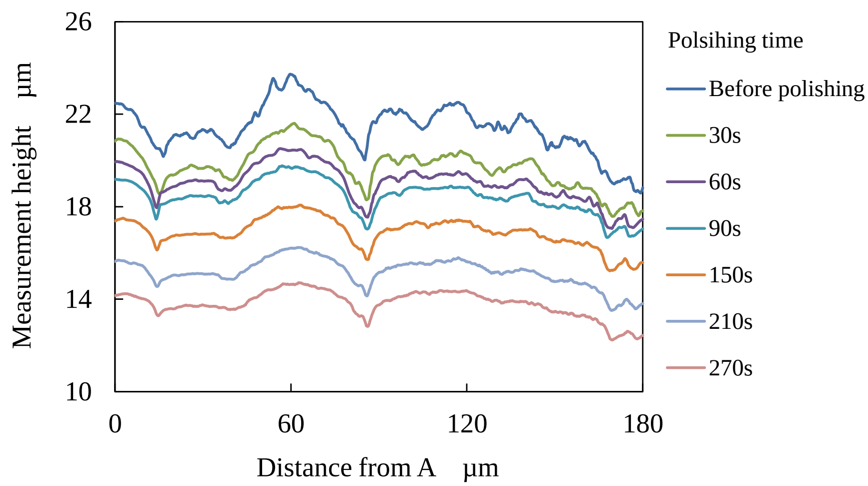
To further understand the influence of vector forces in each injection angle condition, an observation of surface morphology transition is conducted. The results of observation are shown in Figure 3-7. For injection angle 90 degrees condition, Figure 3-7 (c), although the polishing media is injected at the highest injection speed condition, 59.5 m/s, no surface flattening was observed. The wavy shape of the initial surface before polishing was still clearly preserved even after 270 seconds of exposure in the polishing process. This is because under the injection angle of 90 degrees, the vertical component force, the bite force was the only contributor. Therefore, no surface flattening was observed with the lowest surface roughness decline rate. This result also revealed that the horizontal component force was essential in flattening the surface. In addition, when compare to the result in Figure 3-3 (c), injection angle at 45 degrees, to Figure 3-7 (c), injection angle at 90 degrees, the injection angle at 45 degrees shows a higher surface removal rate in terms of height (refer to the vertical axis in the graph). This means that the amount of surface removed was greater. Moreover, the injection angle of 45 degrees has the highest surface roughness decline rate as shown in Figure 3-6. Hence, from these results, it was apparent that the balance between the vertical component force and the horizontal component force was also important to maximize the efficiency of the polishing process.



(a) Injection angle 15°



(b) Injection angle 75°



(c) Injection angle 90°

Figure 3-7 Profile shape of the polished surface in each injection angle.

3.3.3 Influence of polishing media water content on the process surface

3.3.3.1 Relation of polishing media water content to its mass and kinetic energy

The relationship between the water content and the mass of the polishing media is shown in Figure 3-8. The mass increased by the increase in water content as shown in the figure. The increment of mass for the highest water content conditions, water content of 50% was about twice of water content of 10%. Figure 3-9 shows the relation between average injection speed and inverter value of the impeller in three different water content conditions.

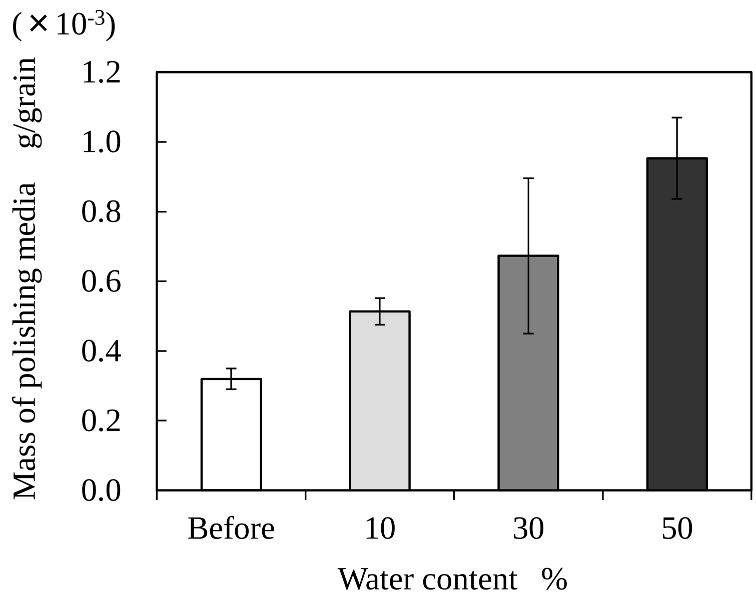


Figure 3-8 Comparison of the weight of polishing media in each water content.

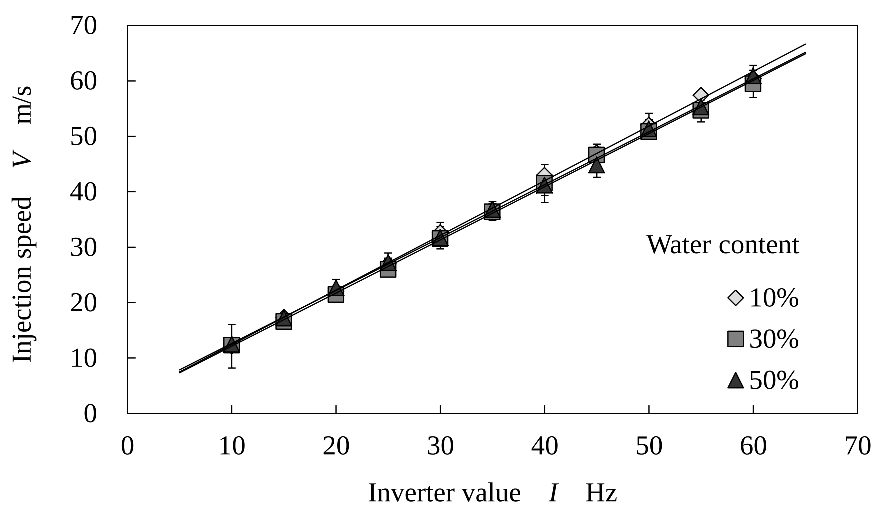


Figure 3-9 Relationship of inverter value and injection speed in each water content.

From Figure 3-9 the relationship of injection speed and inverter value shows a linear relationship with almost same inclination in all water content conditions. This linear relations could be express by the following equation.

$$V_{10\%} = 0.99I + 2.56 \quad (3\text{-}1)$$

$$V_{30\%} = 0.96I + 2.53 \quad (3\text{-}2)$$

$$V_{50\%} = 0.95I + 3.10 \quad (3\text{-}3)$$

From these equations, the kinetic energy for each water content condition is calculated and the obtained result are shown in Figure 3-10.

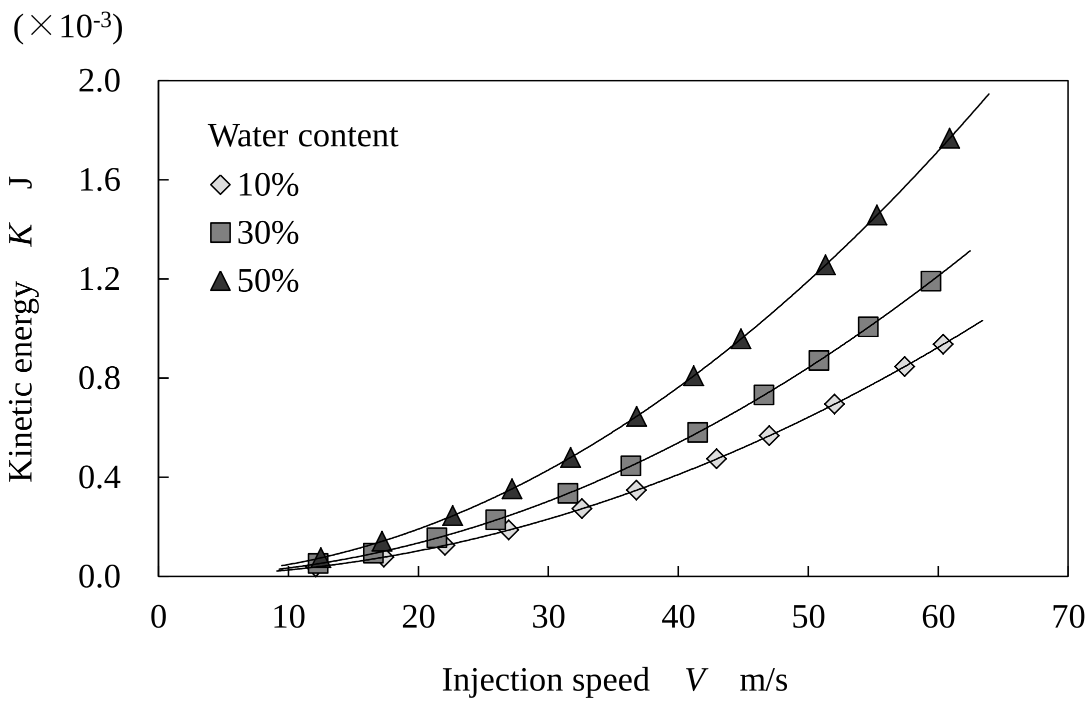


Figure 3-10 Comparison of kinetic energy in each water content.

From Figure 3-10, the relationship of kinetic energy and injection speed in each water content condition can be expressed by the following equation.

$$K_{10\%} = 0.257 \times 10^{-6} V^2 \quad (3\text{-}4)$$

$$K_{30\%} = 0.337 \times 10^{-6} V^2 \quad (3\text{-}5)$$

$$K_{50\%} = 0.477 \times 10^{-6} V^2 \quad (3\text{-}6)$$

3.3.3.2 <u>Influence of mass of the polishing media to the surface roughness</u>

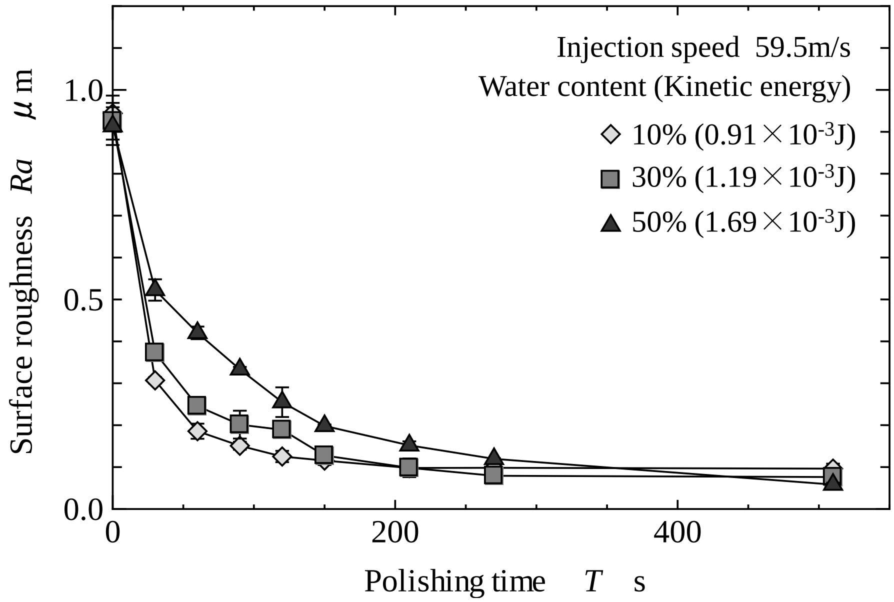


Figure 3-11 Relation of polishing time and surface roughness in each water content condition under injection speed 59.5 m/s and injection angle 45 degree

Figure 3-11 shows the relation of the surface roughness and polishing time in each water content condition at the maximum injection speed of 59.5 m/s and injection angle of 45 degrees. From this figure, it was observed that the surface roughness values, for all water content conditions, showed a sharp decline shortly after the start of polishing. However, after a certain polishing time period, this declining trend stopped and the surface roughness saturated and moreover the value of the surface roughness saturation level was found different for each water content condition. In addition, the polishing media with a water content of 10% shows the highest surface roughness decline rate, where up until 200 seconds of polishing, the surface roughness value was the lowest compared to other water content conditions before it becomes saturated. After 200 seconds of the polishing process, the surface roughness for the water content of 30% transcends the water content of 10% to become the lowest and saturated. Lastly, after 400 seconds of polishing, the surface roughness value for the water content of 50% transcends the saturation value of water content of 30% to become the lowest and saturated. Therefore, from these phenomena, it was observed that as the water content of the polishing media increased, the time for the surface roughness value to saturate also increased and the surface roughness saturated to the lowest value.

To further understand these phenomena, the surface was observed using a laser microscope after each polishing time period. The observation results are shown in Figure 3-12. From this figure, it was observed that at the initial polishing process, up to 30 seconds, the surface polished with water contents of 30% and 50% still looks rough with little presence of peak and valley. However, in the case of a water content of 10%, although the surface looks flat without any trace of peak and valley, numerous scratch marks can be clearly observed. This scratch mark was left by the abrasive grain during the polishing process. Further observation of the polishing process up to 510 seconds, the surface polished under water contents of 30% and 50% becomes smooth and clean while, in the case of the water content of 10% condition, scratch marks were still being observed on the flat surface, refer Figure 3-13.

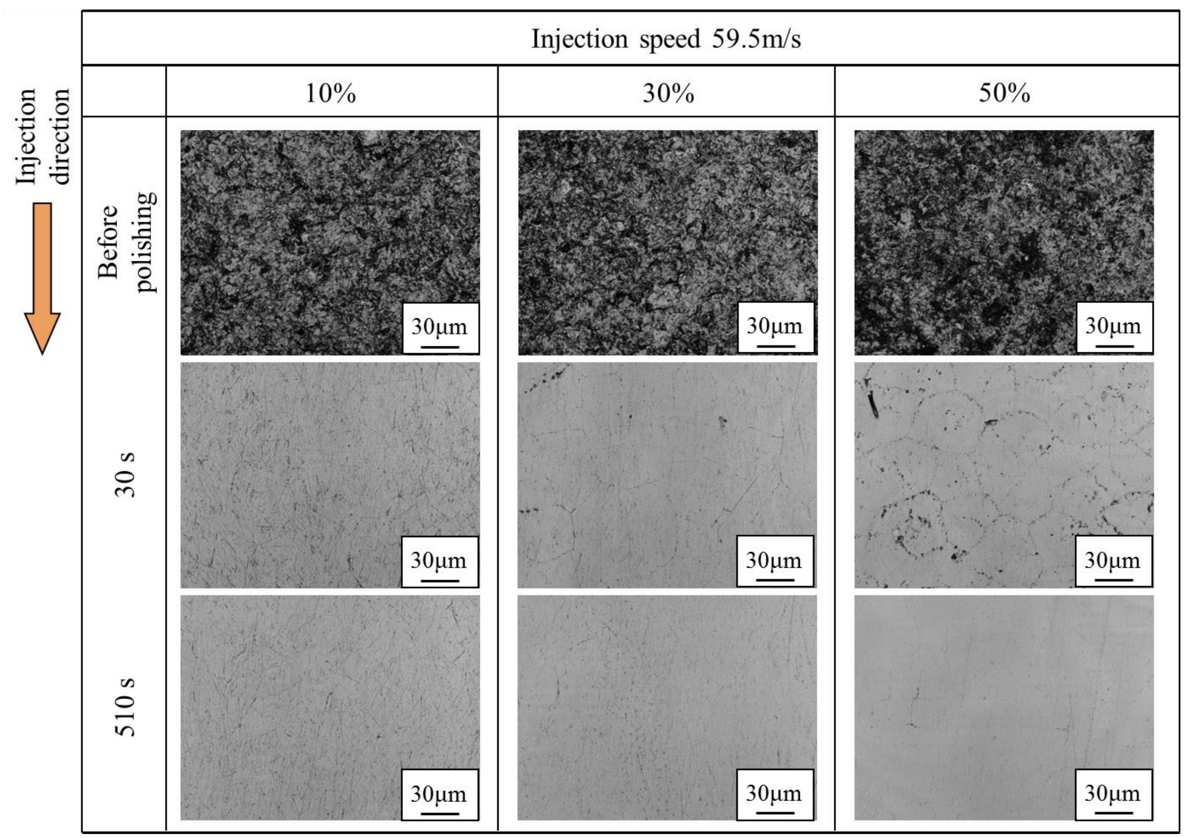


Figure 3-12 Observation result of polished surface in each water content condition.

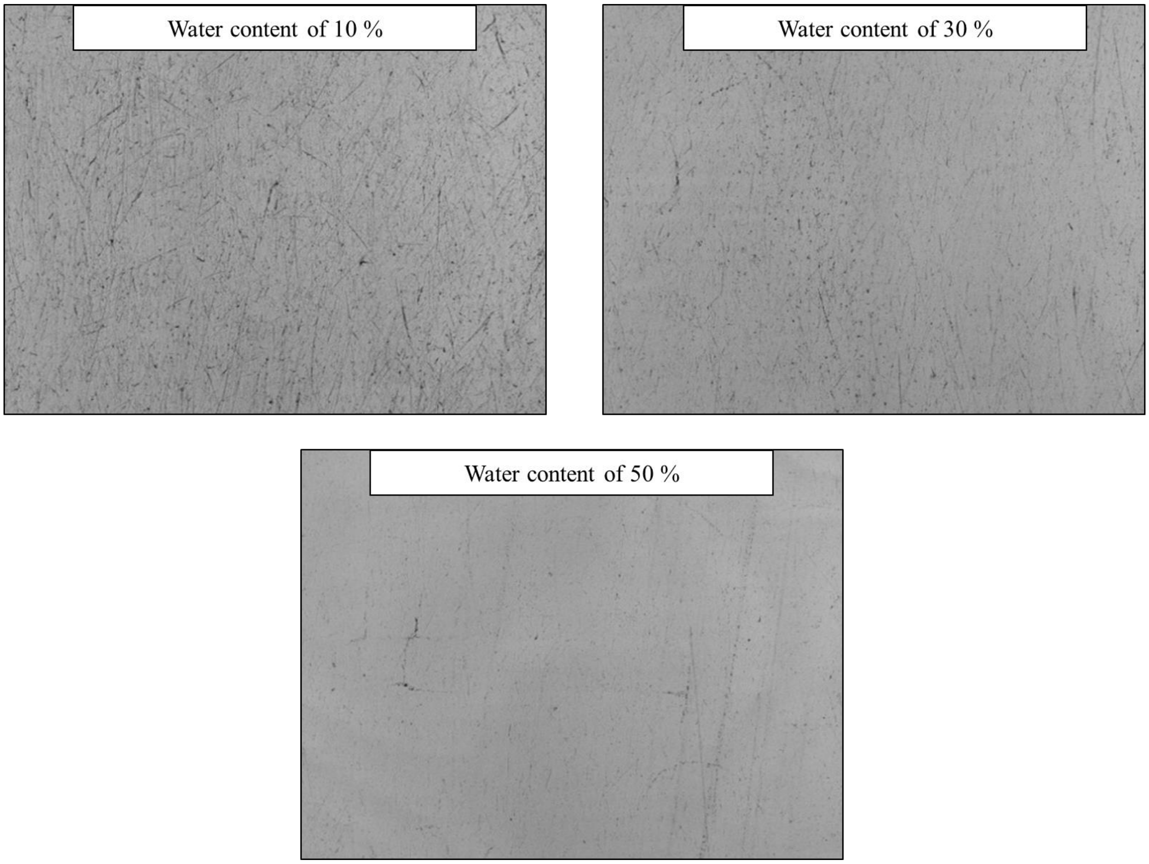


Figure 3-13 Greater view of scratch mark observation on the surface polished for 510 seconds in each of water content conditions.

From this result, it was concluded that the polishing media abrasive grain bite force and grinding force that polished the surface with the water content at 10% was higher than the other water content conditions. Therefore, the surface roughness decline rate was the highest. However when saturated, it saturates to a higher degree than the other water content conditions and left numerous scratch marks on the surface. The influence of water content inside the polishing media was considered to be the factor that changes the polishing characteristics of the polishing media. Changing the water content of the polishing media changed its viscoelastic property and cooling capacity which affects its polishing behavior on the process surface. Further investigation of the polishing characteristics and the viscoelastic property of the polishing media is explained in next chapter, **Chapter 4**.

3.4. Summary

In this chapter, the blast polishing process was used to polish the carbide surface. The relationship between the polished surface properties and the factors involved in this polishing was investigated in order to reveal the influence of various factors in this polishing process on the surface condition of cemented carbide substrate. The result obtained in this study is summarized as below.

[Influence of polishing media injection speed on the process surface]

1. It appeared that in higher injection speed such as 31.5 m/s and higher, shortens the time to achieved smooth flat surface and also shows the tendency to saturated faster.
2. From the observation of the surface morphology it was revealed that the surface morphology significantly changes after 30 seconds of polishing.
3. The polishing rate for the peak is the highest, and then follows by flat plain surface, and finally the valley.
4. It was clear that a high injection speed of the polishing media was an effective means to reduce surface roughness within a short period of time.

[Influence of polishing media injection angle on the process surface]

1. It was revealed that an injection angle of 45 degrees shows the highest surface roughness decline rate and injection angle 90 degree shows a very slow rate. Hence, in order to decrease the surface roughness value of the work surface, the horizontal component force which is the grinding force contribution must be greater than vertical component force which is the bite force.
2. No surface flattening could be observed for an injection angle of 90 degrees compared to other injection angles conditions. This has revealed that the horizontal component force was important for flattening the process surface.
3. When compare among injection angle 45 degree and 90 degree in the case of surface removal amount, it was revealed that the highest removal rate is under injection angle 45 degree condition.
4. Injection angle of 45 degrees was suggested as the most efficient angle to achieve a high surface

roughness decline rate and a high amount of surface removal due to the optimized amount of force in both vertical and horizontal component force.

[Influence of polishing media water content on the process surface]

1. It was revealed that the surface roughness declining rate for the water content of 10% soon after the start of polishing is the highest, and then follows by water content of 30% and finally 50%. However, finally at the saturation level, water content of 10% is in the highest level and water content of 50% is in the lowest level.
2. A grinding mark presence was observable on the surface under polishing media water content of 10%, and these grinding mark presences was less observable in higher water content. The reason for this phenomenon to occur is due to the change in characteristics in the polishing media when water content is change.
3. The change in mass and rigidity of the polishing media is the factor that influences the polishing characteristics including the cooling performance on the work surface during polishing.

4. Polishing mechanism on cemented carbide substrate by blast polishing process

4.1. <u>Introduction</u>

In the previous chapter, it was revealed that in the condition when polishing media water content is constant, the surface roughness of the cemented carbide substrate decline in a short period of time and saturated to the lowest value under highest injection speed conditions. Furthermore, regarding the factors of polishing media injection angle, the injection angle of 45 degrees was suggested as the most efficient angle to achieve a high surface roughness decline rate and a high amount of surface removal due to the optimized amount of force in both vertical and horizontal component force.

In addition, in the case of when changing the rate of polishing media water content, where the kinetic energy of the polishing media increase proportionally with the increase of injection speed, reveals that instead of its high polishing rate under lower water content condition, the surface roughness saturate higher than the saturation value of the higher water content conditions. These such specific polishing characteristics, is thought due to the factor of the polishing media elasticity and this elastic characteristics dependant on the water contain inside the polishing media.

In this chapter, as a follow-up studies on the polishing mechanism on cemented carbide by the blast polishing method, further investigation is conducted to evaluate the effects of the polishing media water content on the polishing mechanism.

4.2. Experimental condition

Experiments of same kinetic energy in each polishing media water content condition were performed at polishing conditions as shown in Table 4-1. This experiment is conducted by adjusting the injection speed using the Eq. (3-4), Eq. (3-5) and Eq. (3-6) calculated in the previous chapter, Chapter 3, section 3.3.3.1, to get the kinetic energy of about 0.8×10^{-3} J in each polishing media water content. The detail polishing media injection speed in each water content under same kinetic energy condition is as shown in Table 4-2. Further, in order to clarify the surface roughness of the saturation value by polishing media with different water content, the polishing time of the experiment was extended to 1560s.

Table 4-1 Polishing condition of same kinetic energy in each polishing media water content condition.

Injection condition	Polishing time (s)	0 - 1560
	Injection quantity (g/s)	36
	Injection angle (deg.)	45
	Width of Nozzle (mm)	5
	Injection distance (mm)	20
Polishing media	Multi-Cone (g)	1000
	Multi-Powder #3000 (g)	30
	Water content (%)	10
		30
		50

Table 4-2 Polishing media injection speed in each water content under same kinetic energy condition.

Injection condition	Kinetic energy (J)		0.8×10^{-3}	
	Water content (%)	Injection speed (m/s)	10	55.8
			30	48.7
			50	41.0

4.3. Result and discussion

4.3.1 Effect of injection speed and water content of the polishing media

Generally, in the type of abrasive polishing by injecting the polishing media with solid particulate substrate, the higher the kinetic energy supplied to the abrasive, the greater the value of abrasive grain to bite the work piece surface (bite force, vertical component force against the processing surface), and to remove the work piece surface (removal force, the horizontal component force against the processing surface). Therefore, the higher the polishing media kinetic energy, the faster the surface roughness value decline after the start of polishing (referred to as polishing rate), on the other hand, due to the abrasive grain bite deeply into the work surface, the surface roughness saturation value shows a trend to saturated higher[32].

Whereas, in this blast polishing method, as shown in the previous chapter, under high kinetic energy conditions, the polishing rate increased and the surface roughness saturation value is decrease lower, which was against the behaviour of the conventional method stated in the above paragraph. Therefore, the suggested mechanism is explained as the following.

In the polishing process by injecting the polishing media type, in the case of substrate having a work hardening property, the workability of the substrate depends on the relationship or the balance of the three parties which is the polishing media kinetic energy, polishing media cooling capacity, and substrate work surface hardening. The relations of these three factors is thought to determine the substrate surface roughness saturation value[33]–[36]. For the conventional polishing method using solid abrasive grain, the work hardening is increased when the kinetic energy higher. But at the same time, since the heat generated during the polishing process is greater than the occurrence of work hardening, as a results, high polishing rate is obtained eventually with higher surface roughness saturation value. For the blast polishing method, since the polishing media is a water contain type, the heat generated on the surface during the polishing process is suppress and cooled by water contain inside the polishing media. Therefore, compare to the conventional method using solid abrasive grain, it is thought that a greater degree of work hardening occurred on the process surface as a result of the heat generated is suppressed.

To confirm the above statement, the relationship between the work surface hardening and the polishing media injection speed was investigated. The result is as shown in Figure 4-1. From this figure, the evidence of work surface hardening was found. The surface hardness increased in comparison to the hardness of the surface before polishing. It was evident that the surface hardness has increased under higher injection speed, resulted to the increased of resistance against the abrasive grain to bite deeply into the work surface. Therefore, the surface roughness saturated lower than the saturation value of the lower injection speed condition. Nevertheless, due to the high impact force, the abrasive grain surface removal was greater which make the surface roughness declined sharply during the initial polishing process. In the study of the work surface hardening effect to machinability, it was revealed that work hardening was less likely to influence machinability in comparison with other hardening methods such as heat treatment[37]. Hence, the influence of process surface hardening to the removal capacity of the process surface was considered to be negligible.

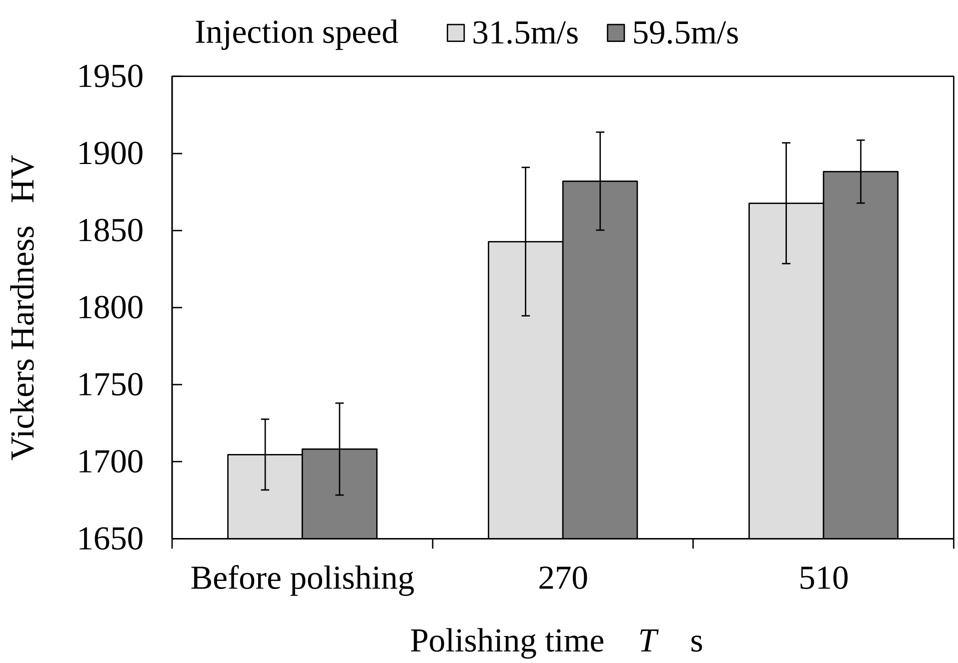


Figure 4-1 Relation of polishing time and hardness in each injection speed under water content 30% and injection angle 45 degree.

It should be noted that, the WC-Co work piece used in this study has the combination of 0.8 µm fine WC particles in homogeneous dispersion with 10% of Co binder. Basically, WC material does not plastically deform, so the plastic deformation and thus work hardening is thought to occur only in Co binder.

4.3.2 <u>Influence of polishing media water content on the polishing mechanism</u>

4.3.2.1 <u>Relation of polishing media water content and surface hardening</u>

In the previous chapter, it was revealed that by changing the water content of the polishing media, eventually changed the mass as well as the kinetic energy of the polishing media. These changes results to a different surface properties when compare to the experiment of changing the polishing media injection speed under constant water content, water content of 30%. Therefore, the changes in material properties and processing characteristics of the polishing media when varying the water content is considered to have had some effect on the polishing mechanism.

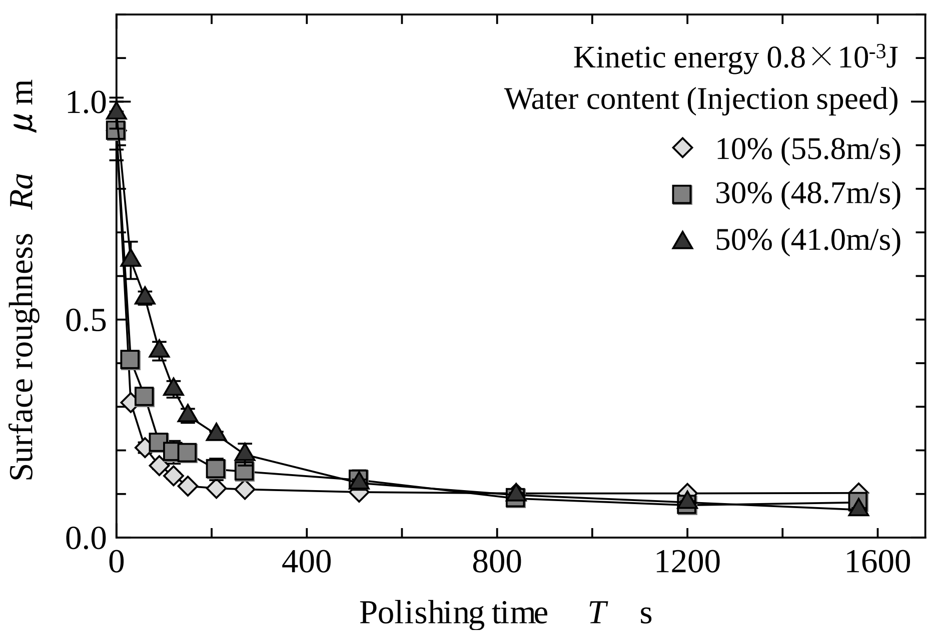


Figure 4-2 Relationship of polishing time and surface roughness in each water content rate with same kinetic energy condition.

In this section, to better understand the effect of the polishing media stiffness on the polishing mechanism, an experiments were carried out to inject the polishing media with different water content to under the same kinetic energy conditions. In order to set the injection speed of the polishing media to the highest speed as possible, in this experiment, the kinetic energy of the polishing media in each water content condition is set to 0.8×10^{-3} J.

Figure 4-2 shows the relation of polishing media polishing time and surface roughness with different water content condition under the same kinetic energy condition. From the figure, the surface roughness decrease immediately after the start of polishing where the lowest water content 10% shows the highest declining rate and then followed by water content of 30% and finally water content of 50%. Furthermore, when saturated, the surface roughness saturation value for water content of 10% is the highest and the water content of 50% is the lowest.

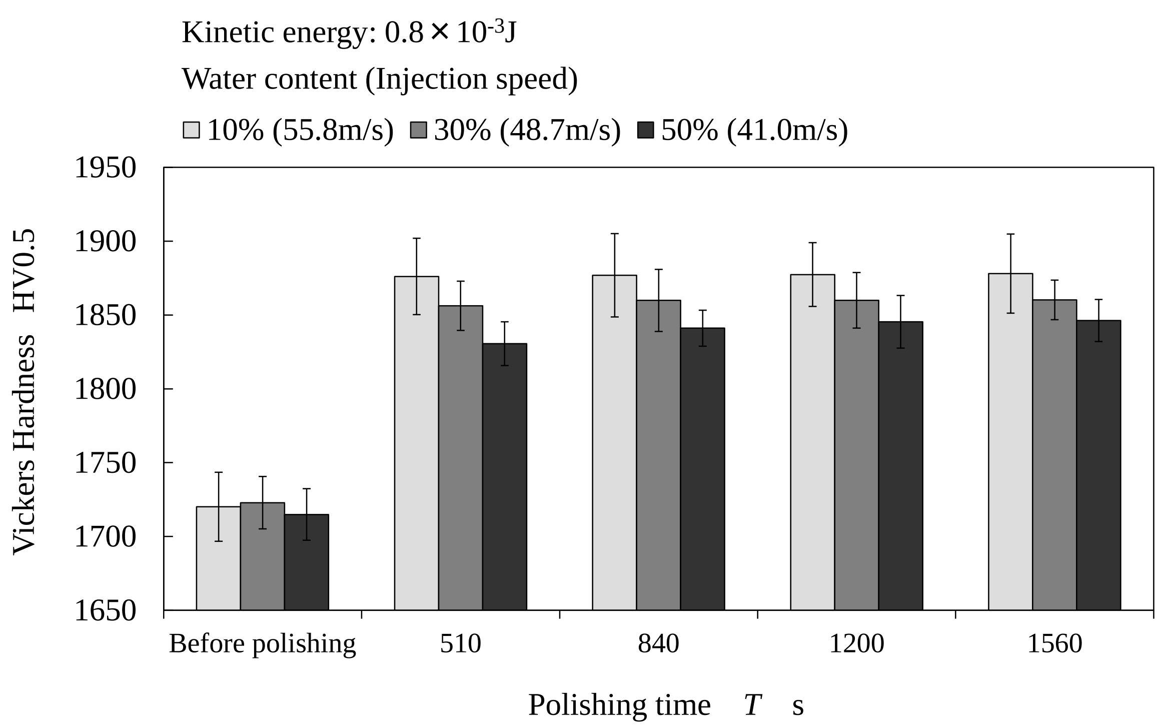


Figure 4-3 Relationship of polishing time and hardness in each water content with same kinetic energy.

In addition, from the above polishing condition, the measurement of work surface hardness is conducted to investigate the work surface hardening occurrence. The result of measurement is shown in Figure 4-3. From the figure, it is clear that the work surface hardening occurs rapidly when polished under lower water content and after certain polishing time the increase of hardness suddenly stop and finally saturated. Also, for the work surface polished under higher water content condition, the hardness of the work surface gradually increase continuously with the increase of polishing time and eventually it was found the differences in the hardness value between each polishing media water content conditions is reduced under longer period of polishing process.

4.3.2.2 Influence of polishing media stiffness on the polishing characteristics

The differences on the substrate work hardening behavior under different polishing media water content conditions in this experiment is because of the different qualities of the polishing media possessed when the water content is changed. In other words, for low polishing media water content condition, with its lower mass, a higher injection speed is required in comparison with other higher water content conditions to reach the same kinetic energy value. At the same time, with low water content condition, it correspond in the increased of polishing media core material elasticity and lowering the cooling capacity. Supposed the kinetic energy of the polishing media in each water content condition is same, the work hardening properties induces on the surface during polishing process can be considered as the same. Here, the differences in the work hardening value between each water content with same kinetic energy conditions is thought to be due to factors in the differences in elasticity properties and cooling capacity of the polishing media. Therefore the relation of polishing media water content and the elastic properties is measured by measuring the static modulus of elasticity of the polishing media. The result of measurement are shown in Figure 4-4.

From this figure, it was revealed that the elastic modulus decreased with increasing of water content. Also, the elastic modulus for the water content of 10% was higher than other water content conditions which were about 10 times greater compared to the water content of 30%, and about 15 times greater compared to water content 50%. Therefore core material of polishing media water content of 10% is considered to have the highest rigidity. We can conclude that the change in the polishing media viscoelastic property will consequently affect the polishing media core material rigidity to support the abrasive grain during the impact with the work surface, hence influence the polishing characteristics on the surface during the polishing process.

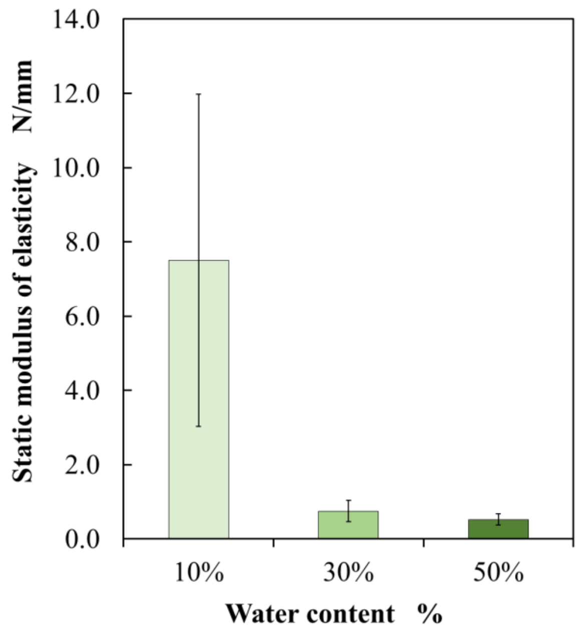


Figure 4-4 Elastic property in each water content.

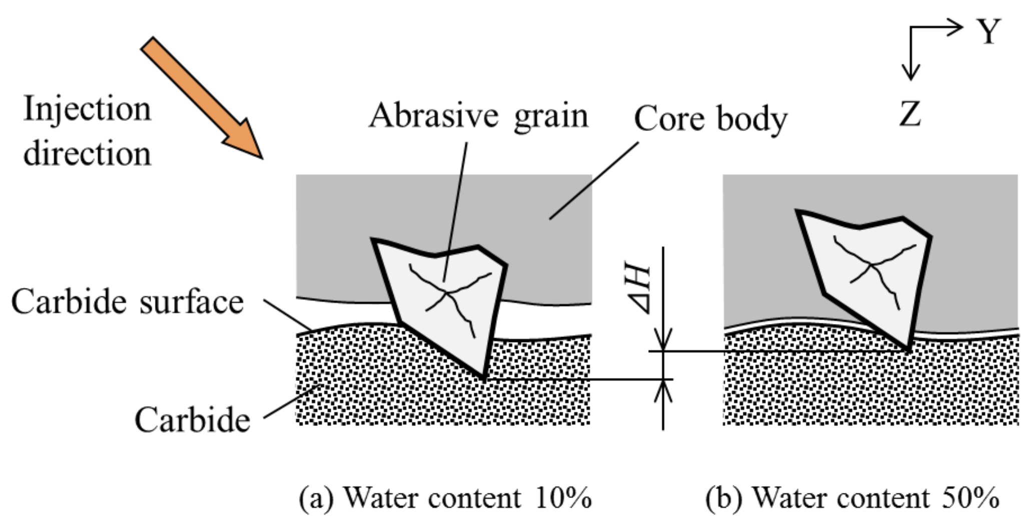


Figure 4-5 Schematic of abrasive grain amount of bite in each water content.

Figure 4-5 shows the illustration regarding the abrasive grain bite amount during the collision with the work surface. Under the water content of 50%, when the polishing media collides, the abrasive grain was forced to move inside the internal part of the polishing media core material by the grinding resistance. This was due to the low rigidity of the core material to support the abrasive grain. In contrary, with the water content of 10%, when colliding with the surface, due to its core material high rigidity, the polishing media was able to repel the grinding resistance. The abrasive grain was barely forced inside the core material, thus allowing the abrasive grain can bite deeply into the surface. The difference between the amounts of bite was specified as ⊿H.

In addition, Figure 4-6 shows the results of observation of the deformation behavior when the polishing media collides with the work surface. While polishing media rigidity was high under water content of 10%, no deformation was confirmed. On the other hand, under water content of 30% and water content of 50%, the deformation was observed and became more evident with the water content of 50%. Furthermore, from the video taken during the observation of the polishing media deformation behavior, the impact force, F applied to the work surface was calculated. From Figure 4-7, the impact force for a water content of 10% was significantly higher in comparison with other water content conditions which were about 3.5 times greater than that of water content 30% and 50%. Therefore, it was proven that the abrasive grain bite force (vertical component of impact force) and the surface removal force (horizontal component of impact force) for the water content of 10% was greater compared to other water content conditions.

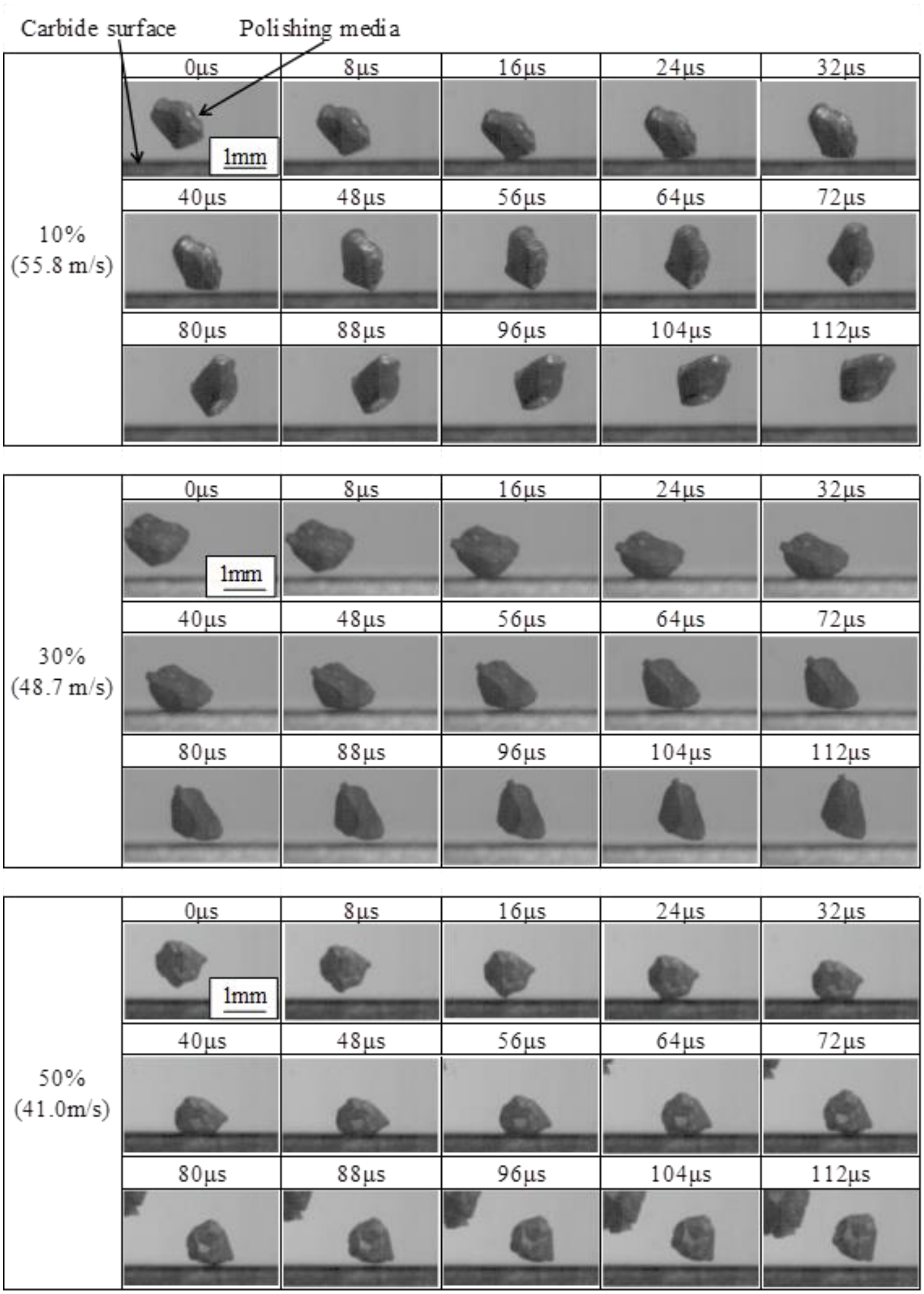


Figure 4-6 Polishing media deformation behavior in each water content condition.

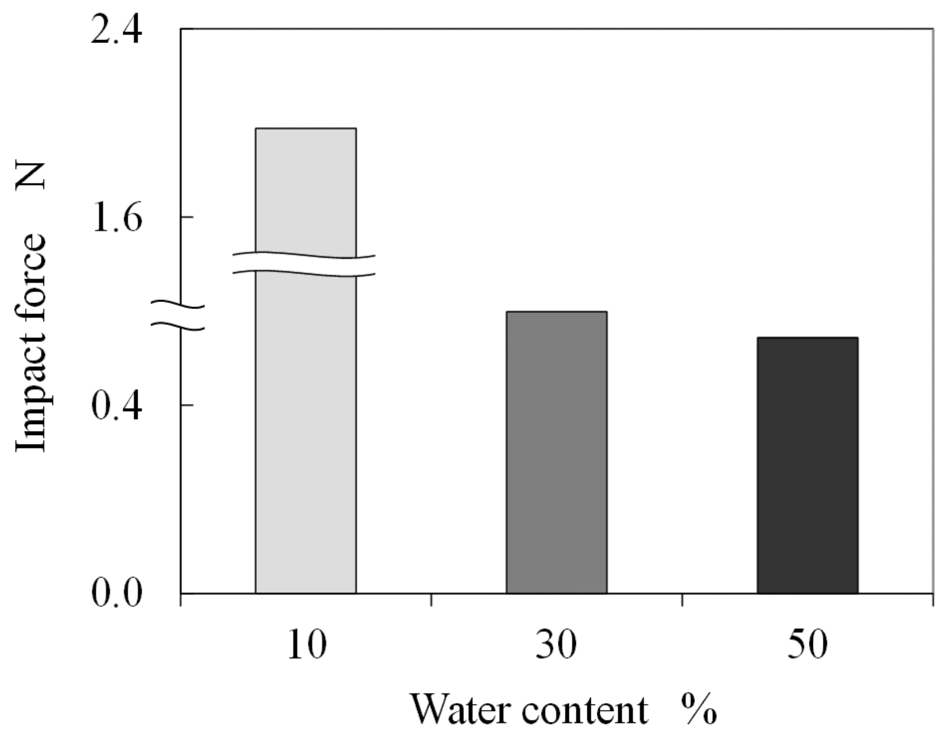


Figure 4-7 Comparison of impact force in each water content.

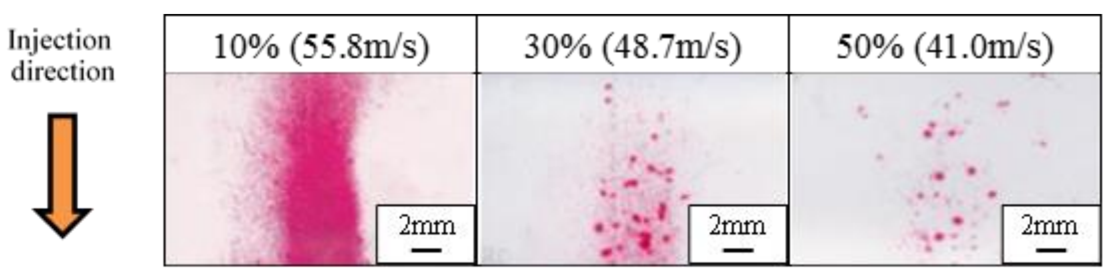


Figure 4-8 Comparison of coloring image in each water content.

In order to aggregate the impact force shown in Figure 4-7, an experiment to measure the pressure distribution to the work surface was conducted using a pressure sensitive film. The results are shown in Figure 4-8. From this figure, the polishing media with highest rigidity, water content of 10%, compared with other water content conditions has the most red coloring indicting a clear evidence that a high pressure has been added on work surface during the polishing process. Since no deformation is confirmed as refer to Figure 4-6, adding this results together with a high impact force described above, the smaller contact area between the polishing media and the work surface compare to other water content conditions can be consider as a factor. Also, a comparison of the water content of 30% and 50% shows that water content of 30% shows a strong red color. However no large different was observed in the impact force result. From the fact of the observation result of the deformation behavior at the time of collision, polishing media water content of 50% shows larger deformation results to a larger contact area between the polishing media and the work surface, it can be consider a lower pressure for water content of 50%.

4.3.2.3 <u>Water content influence on the polishing characteristics</u>

Figure 4-9 shows the schematic diagram of the polishing media abrasive grain when processing the surface under different water content conditions. The abrasive grain indicated by the dotted line was the abrasive grain position when it collides with the process surface. At the beginning of the collision, the abrasive grain bites the surface. However, from the reaction force received by the process surface to repel the impact, the abrasive grain was forcedly pushed inside the internal part of the polishing media core material. In the case of polishing media with a water content of 10%, due to its high rigidity, the displacement amount of the abrasive grain forced inside the polishing media was small compared to the polishing media water content of 50%. Therefore, the abrasive grain can bite deeply into the process surface.

During the collision, due to the high impact force for a water content of 10%, the force to remove the work surface, referred to as grinding length, was higher when compared to a water content of 50%. Moreover, with a water content of 50%, some of the energy was lost by the greater polishing media deformation, refer to Figure 4-6, that weakening its cutting ability. As a result, the water content at 10% resulted in a high surface roughness decline rate compared to the other water content conditions, however when the surface roughness becomes saturated, it saturates higher than the other conditions. Additionally, the existence of scratch marks on the polished surface using a water content of 10% was due to the abrasive grain bite deeply into the work surface. Hence, it was clear that water content influences the viscoelastic property of the polishing media which affects its polishing characteristics and eventually results in a different polished surface condition after the polishing process.

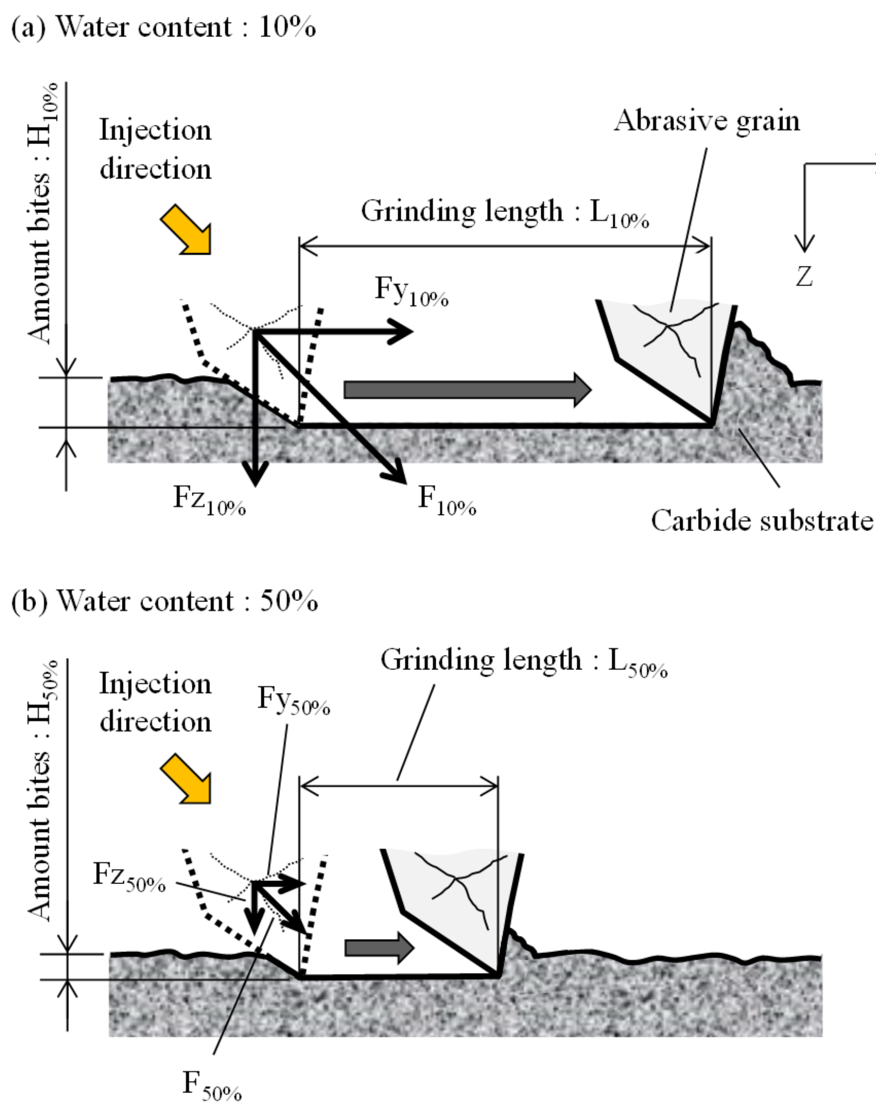


Figure 4-9 Schematic of relationship between grinding length and amount bites in each water condition.

4.4. Summary

In this chapter, further investigation is conducted to evaluate the effects of the polishing media water content on the polishing mechanism. The result obtained in this study is summarized as below.

1. When polishing the cemented carbide at the polishing media water content of 30%, the hardness of the processed surface increase in accordance with the increase of injection speed. Therefore, it was considered that although the force to remove the process surface is increased with the increase of injection speed, due to the increase of the hardness of the process surface, the amount of abrasive grain bite the surface is reduced. As a results, smooth process surface can be obtained in a short period of time.
2. Regarding the effect of polishing media water content to the work surface, it was revealed that the surface roughness decline rate for the water content of 10% was the highest and then followed by a water content of 30% and finally 50%. However, the water content of 10% gave the highest level of saturation while water content of 50% has produced the lowest value.
3. The result of the polishing media elastic modulus revealed that the modulus of elasticity for the water content of 10% was 10 times higher of that for a water content of 30% and was 15 times higher than for a water content of 50%.
4. From the impact force measurement result, it was revealed that the impact force water content of 10% was significantly higher compared to other water content conditions which are about 3.5 times the water contents of 30% and 50%.
5. In conclusion, the water content of the polishing media highly influences the polishing characteristics of this blast polishing method. By changing the amount of water absorbed, the viscoelasticity of the polishing media was changed. Hence, the rigidity of the core material to support the abrasive grain was also changed which resulted in different impact force applied to the work surface during the collision. This eventually affects the polishing behavior of the process and resulted in a different finished surface condition.

5. Optimal surface property of carbide drill for aluminum alloy cutting

5.1. Introduction

In the first part of this thesis, the polishing mechanism of the blast polishing process on cemented carbide substrate has been revealed and becomes clear. However, fewer cases had been reported regarding the influence of blast polishing treatment when actually applied to the cutting tools surface. Therefore as the second part of this thesis, the influence of surface modification by the treatment using blast polishing process to the cutting performance of the cutting tool is investigated.

Recently, several research on the surface modification on the cutting tool surface had been conducted in order improves the cutting tool durability. For this purpose, the evaluation of the cutting tool performance during the cutting process, such as the cutting tools ability to reduce the cutting resistance and its ability to increase the adhesion resistance is the main issue focused in this field. In order to increase the adhesion resistance on the cutting tool, the surface modification such as the development of the micro texture on the tool surface using laser technology has been developed[6]–[13]. These textures have been successful in improving the anti-adhesion by the reduction of real contact area and storage of the lubricant. But, these researches focused on implanting the micro textures on the surface of the cutting tool for milling and turning operations. There are very few research has been conducted regarding the micro texture fabrication on the cutting tool for drilling operation. This is due to its complex curves surface which makes the fabrication process difficult. However, there are exists a uniform micro textures (hereafter refer as grinding mark textures) on the drill flute surface caused by the grinding machines during the production of the drill. Therefore, a research is required to study the effect of these grinding mark textures on the drill flute surface to the cutting performance of the drill. It is thought that the micro textures in the drill flute surface somehow can improves the adhesion resistance as these textures improves the cutting performance of the cutting tool for milling and turning process[6]–[13].

On the other hand, it has been reported that surface modification by mirror polished the drill flute surface is proven to reduce the cutting resistance and improves the chip evacuation[16], [17]. This technique completely removes the grinding mark textures on the tool surface. However, surface texturing method and mirror polished method is clearly shows a contradictory. Moreover, the drill flute surface is long and has complex shape surface which is separated into two main part which is the rake face and guide flute. Hence, the optimal surface condition for each part of the flute surface is still not clear.

In this chapter, we propose the development of the micro texture by controlling the grinding mark, which already exist on the tool surface by using the blast polishing process. An actual polishing was applied on the cutting tools (uncoated carbide drill) flute surface to control the texture of the grinding mark. Based on the results obtained from the previous chapter, several polishing parameters that has been revealed as the most effectives for achieving optimization in polishing process is chosen and applies to further confirms the effectiveness of these optimized parameters as the treatment method on the drill flute surface. The convex and concave shape of the grinding mark is modified to investigate the optimal grinding mark textures to increase the adhesion resistance. Also, to investigate the effect of mirror polished surface, the grinding mark textures is completely removes by the polishing process. In addition, it is thought that a different surface condition required for the rake face and guide flute surface. To investigate the optimal surface condition in both part of the surface, a study of changing the polishing range of the drill flute is also conducted.

The cutting performance are tested by comparing the cutting performance of the drill with and without polishing treatment during the drilling of aluminum alloy, ADC12 in flooded condition using external coolant. The drilling performance was assessed by measuring the cutting force (thrust force) generated during drilling test and by observing the adhesion behavior of the aluminum on the drill flute surface after the drilling process.

5.1.1 **Drill flute surface geometry and nomenclature**

Figure 5-1 shows the schematic of the drill flute surface. The drill flute surface is from the combination of the rake face and guide flute. The rake face, is the surface over which the chip, formed in the cutting process and mostly where the adhesion takes place. It has large effects on cutting resistance, chip disposal, cutting temperature and tool life. The guide flute is the helical grooves in the body of the drill to permit removal of chips, and to allow the cutting fluid to reach the cutting edge. These two parts working environment highly influences the cutting performance of the drill. An abrupt change of the working environment of these parts worsen the drill performance that causes to the increase of the cutting force during drilling and chip clogging inside the holes when the flow of chip discharged is disturbed. Therefore, it is important to evaluate the performance of both drill parts to understand the optimal surface conditions of those parts respectively.

At first, in order to study the optimal grinding mark condition on the drill flute surface as well as to investigate these grinding mark influence on the cutting performance of the cutting tool, the polishing treatment is conducted by polishing drill flute surface in all flute range including the rake face. Further in this study, the polishing treatment is change by changing the polishing range of the guide flute in order to study the optimal surface condition of the guide flute surface.

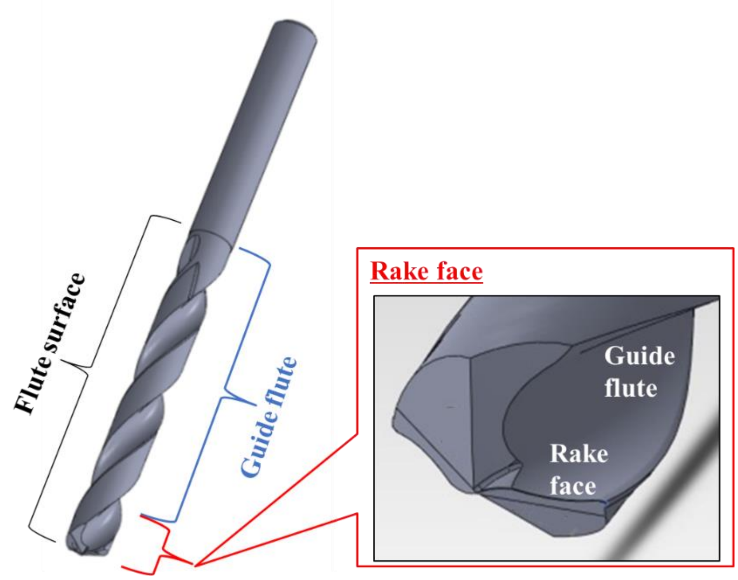


Figure 5-1 Schematic diagram of the drill flute nomenclature and geometry

5.2. Experimental conditions

Table 5-1 shows the polishing condition by blast polishing process on the cutting tool flute surface. The maximum polishing media injection speed, 59.5 m/s, is chosen as it has been revealed in the previous chapter as the most efficient speed in this blast polishing process. Polishing media with water content of 10%, 30% and 50% is used to study the influence of water content to the surface condition and cutting performance of cutting tools. While in the study of the influence of injection angle and polishing time, water content of 30% is chosen. The reason for choosing the water content of 30% is explained in the results and discussion section.

The cutting test was conducted under the conditions shown in the Table 5-2 in any experiment, the cutting resistance for cutting tools treated under each condition.

Table 5-1 Injection condition for researching effect on cutting effect

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Investigated polishing parameters</td></tr>
<tr><td>Water content condition</td><td>Injection angle and polishing time condition</td></tr>
<tr><td rowspan="6">Injection condition</td><td>Injection angle (deg.)</td><td>45</td><td>45, 90</td></tr>
<tr><td>Polishing time (min/flute)</td><td>3</td><td>1, 3</td></tr>
<tr><td>Injection speed (m/s)</td><td colspan="2">59.5</td></tr>
<tr><td>Injection quantity (g/s)</td><td colspan="2">36</td></tr>
<tr><td>Nozzle width (mm)</td><td colspan="2">8</td></tr>
<tr><td>Injection distance (mm)</td><td colspan="2">20</td></tr>
<tr><td rowspan="5">Polishing media</td><td>Multi-Cone (g)</td><td colspan="2">1000</td></tr>
<tr><td>Multi-Powder #3000 (g)</td><td colspan="2">30</td></tr>
<tr><td rowspan="3">Water content (%)</td><td>10</td><td rowspan="3">30</td></tr>
<tr><td>30</td></tr>
<tr><td>50</td></tr>
</table>

Table 5-2 Condition of cutting test

Cutting diameter (mm)	10
Cutting speed (m/min)	100
Feed rate (mm/rev)	0.15
Coolant type	External/FGE360
Hole depth (mm)	28 (Blind hole)
Work piece	ADC12

5.3. Results and discussions

5.3.1 Surface condition of the flute surface before polishing treatment

The grinding mark on the drill flute surface was left by the grinding machine during the production of the drill. In order to investigate the optimum surface condition of the drill flute surface, at first the grinding mark condition before the treatment must be evaluated. Then in the next section, the grinding mark condition in terms of the pitch and depth of the concave and convex shape is controlled by the treatment using blast polishing process.

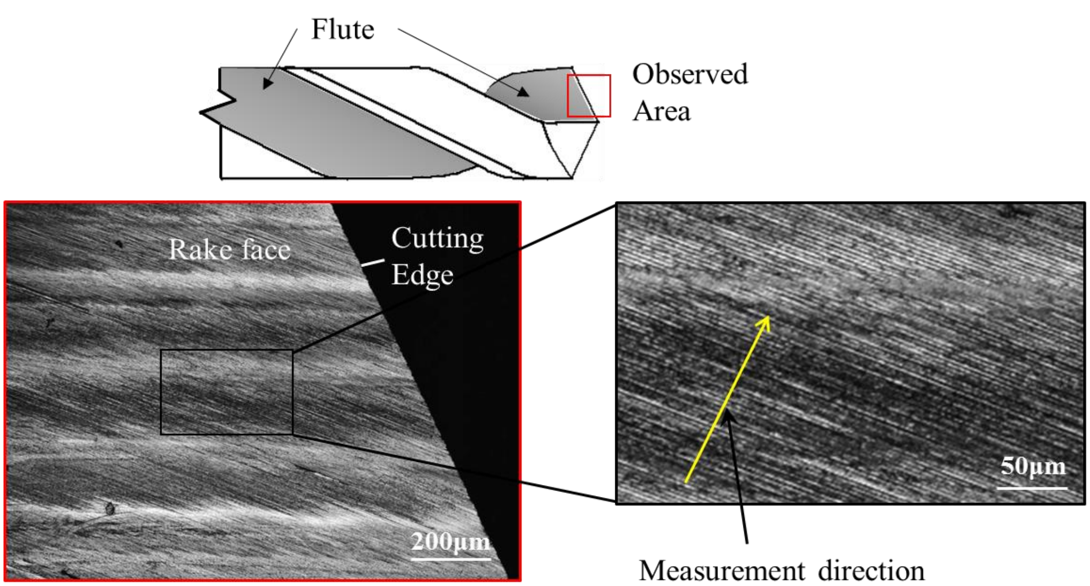
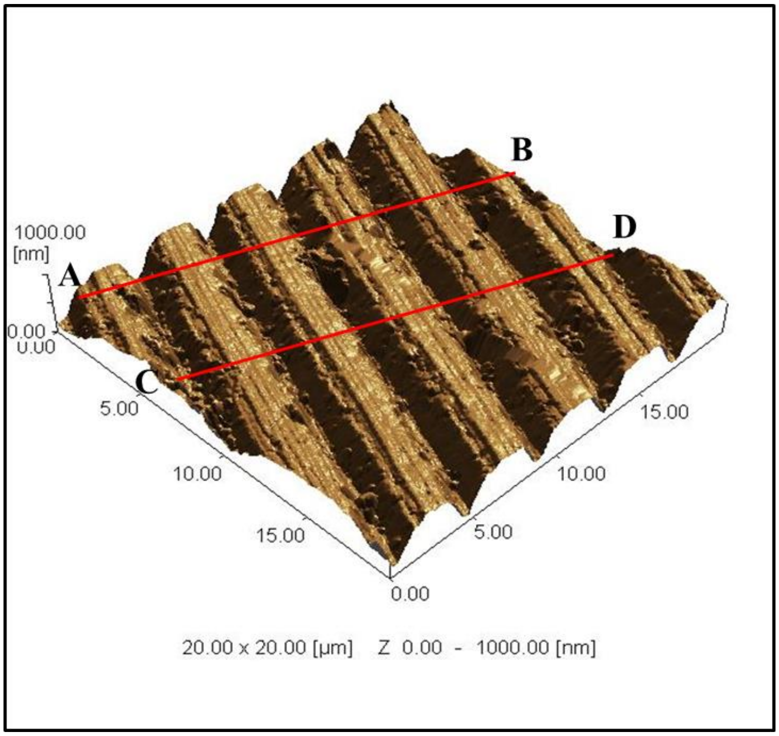
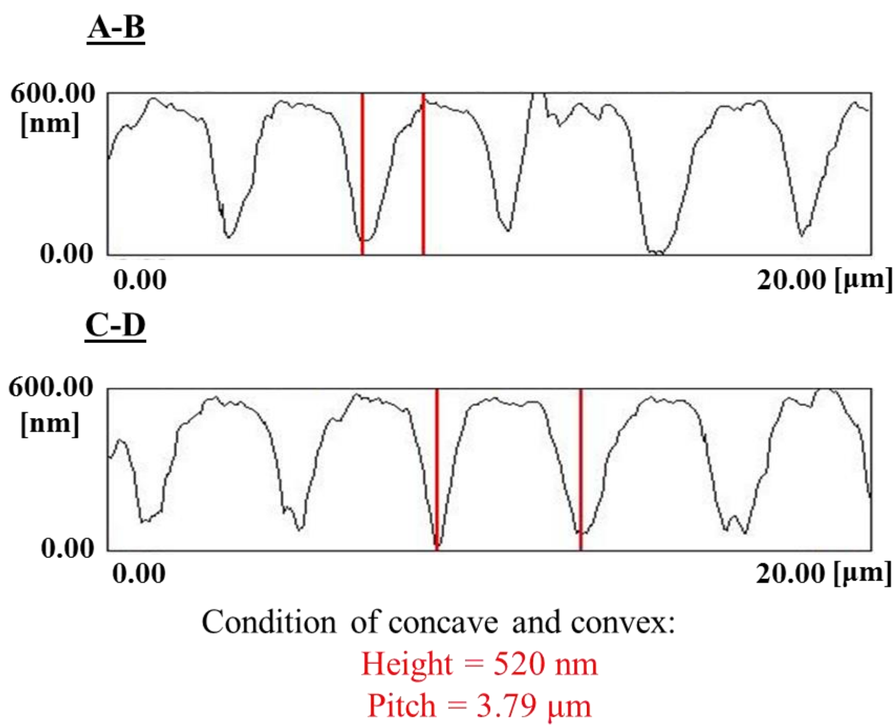


Figure 5-2 Observation result of grinding marks properties on tool flute surface.



(a) Surface topography in 3D



(b) Surface profile of concave and convex

Figure 5-3 AFM surface topography and surface profile of the untreated drill flute surface

Figure 5-2 shows the observation result by laser microscope of the grinding mark condition on the drill flute surface. From this figure it is clear that the grinding mark condition is uniform and its direction is parallel to each other. Further observation by AFM is conducted to further observe the surface topography and surface profile of the grinding mark by evaluating its pitch and depth. The measurement direction is conducted perpendicular with the grinding mark direction. Result of AFM measurement is shown in Figure 5-3. From this figure, it is observable that the concave and convex shape of the grinding marks are constant. The pitch of the grinding marks are about the average of 3.79 μm and the depth of the concave is in the average of 520 nm.

5.3.2 Influence of surface treatment by blast polishing process to the cutting performance

5.3.2.1 Surface treatment by changing the polishing media water content

From the previous chapter, it was clear that the surface roughness was reduces in a short time regardless of polishing media water content condition. Therefore, in this section, the influence of the surface treatment on the drill flute surface by smoothing the surface using the polishing media in each water content condition is investigated. The AFM surface observation after the polishing time in each polishing media water content conditions under injection angle 45 deg. is shown in Figure 5-4. From this figure, it can be observed that for all water content conditions, the grinding mark that exist on the flute surface before the polishing (refer Figure 5-2) is completely removed by the polishing media after the polishing process. However, the surface polished under water content of 10% shows a lot of scratch mark presence when compare to other water content conditions. The scratch mark is considered to be due to the high stiffness of the polishing media core material as described in the previous chapter. From the AFM profile measurement result shown in the figure, the height between the peak and valley of the surface profile is measured. The height of the profile under water content of 30% is the lowest compare to other surface profile conditions. This results indicated a smooth and clean surface was obtained under the polishing process by water content of 30%. The height of the surface profile for water content of 50% is the highest where the uniform shape of the grinding mark is still slightly observable. On the other hand, a rough surface profile was observed which is thought to be the profile of the scratch mark left by the abrasive grain during the polishing process.

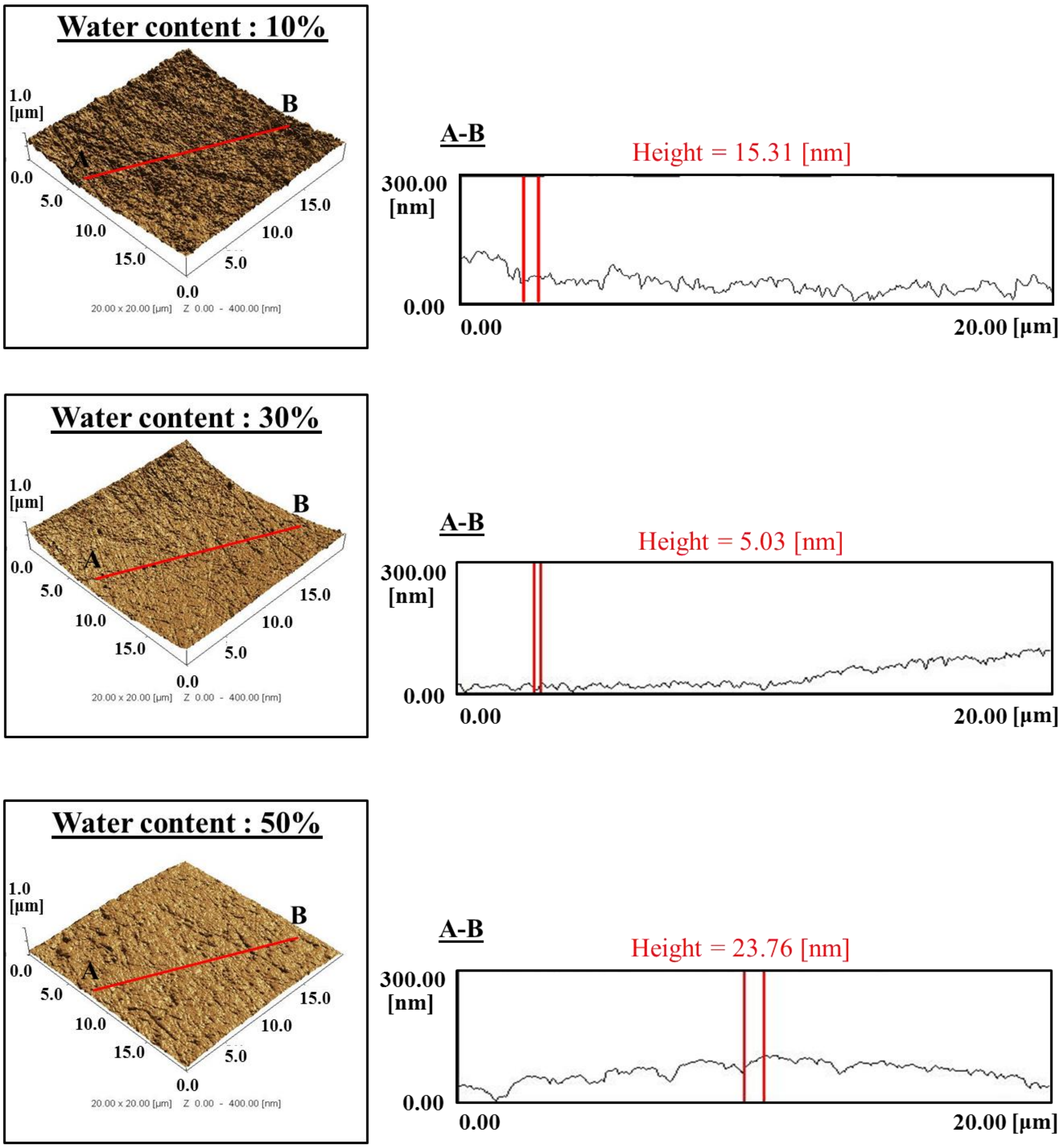


Figure 5-4 AFM surface topography and surface profile after polishing treatment in each water content conditions under injection angle 45 deg.

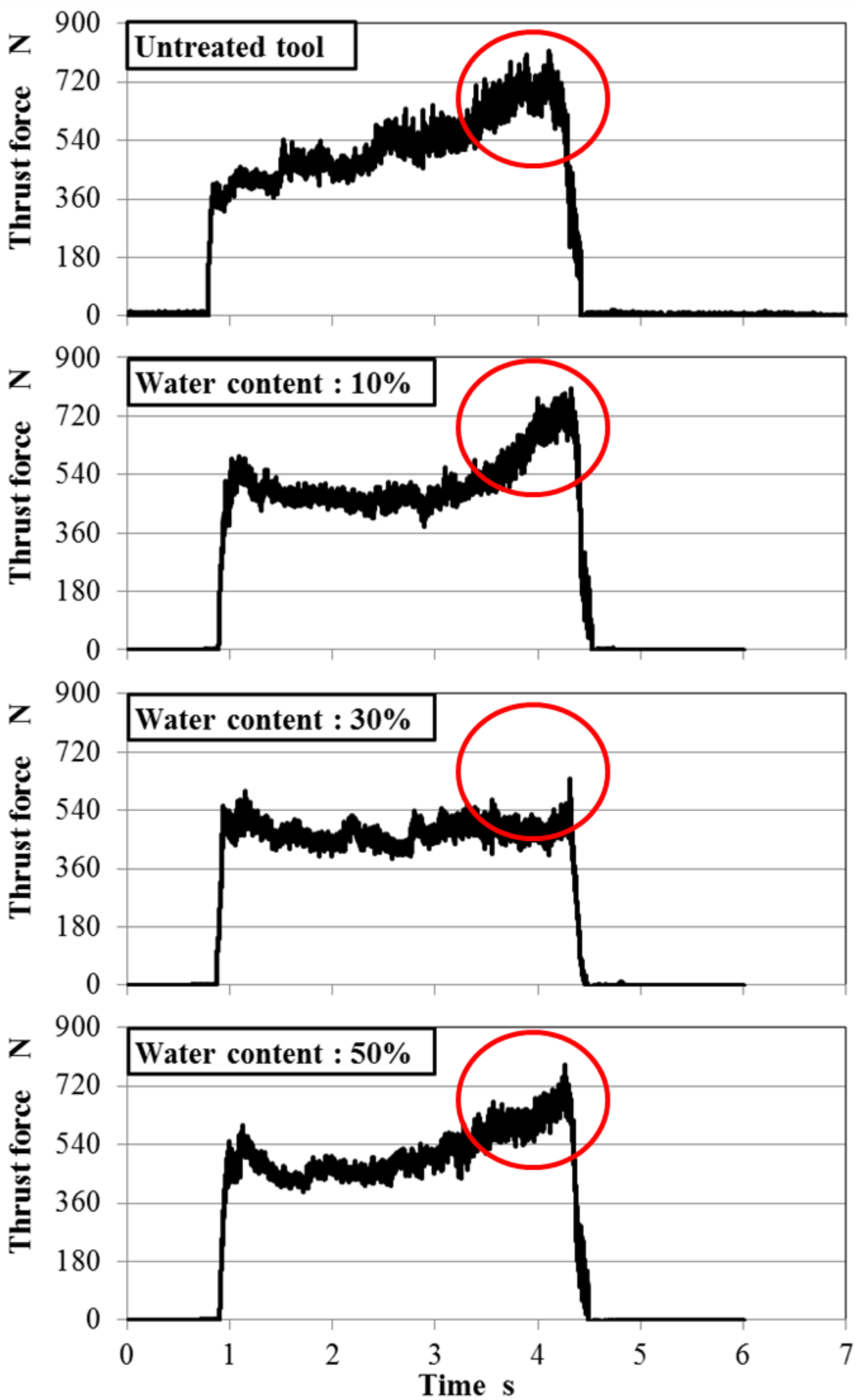


Figure 5-5 Comparison of cutting force of the untreated drill and the drill treated in each water content condition under injection angle 45 deg.

A cutting test is conducted to study the influence of these surface properties on the cutting performance by evaluating the cutting resistance during the drilling process. As for comparison, the cutting test is also conducted to the drill without any treatment (hereafter refer as untreated drill). Figure 5-5 shows the relation of cutting resistance and drilling time measured during drilling second holes for each drill conditions. From this figure, it is observable that no significant changes in the cutting resistance for the drill treated with water content of 10% and 50%, when compare to the untreated drill. On the other hand, drill undergo treatment with water content 30%, it was confirm that the cutting resistance is reduces, as indicate by the red circle in the figure. The cutting force at the entrance until the end of the hole shows no sudden rise. In contrary, the untreated drill and drill treated with water content of 10% and 50% conditions, the cutting resistance continue to rise as the drilling goes deeper inside the hole.

The drill treated with water content of 30%, as observed by the AFM in Figure 5-4, with it smooth surface condition, it provides less friction for the flow of lubricant and sufficiently reached the rake face. On the other hand, the tool treated with water content of 10% has a lot of scratch on the surface. For the untreated tool and tool treated with water content of 50%, there are grinding mark exists on the surface. Therefore, these scratch mark and grinding mark states results in the increase of friction between the surface and the chip and creates a difficult condition for the lubricant to flow smoothly along the guide flute to reach the rake face inside the hole. As a result, the execution of the generated chip inside the hole is disturbed. In addition, the rake face is the major part that comes with the direct contact with the chip. Therefore, the supply of lubricant is essential for the rake face because the lubricant aid the cutting process by lubricating the interface between the tool and the chip. By preventing friction at this interface, some of the heat generation is prevented. The lubrication also helps prevent the chip from being welded onto the tool. Hence, when the lubricant is not sufficiently supply to the rake face, the working condition on the rake face worsen and the formation of Build-Up Edge (BUE) is likely to form on the surface. This can be assigned to a change in the tribological conditions along the tool rake face[38]. Thus, these two factors contributes to the rise of the cutting forces when the drilling goes deeper inside the hole.

From these results, it can be conclude that, for lower water content conditions, due to polishing media high elasticity, its creates a lot of scratch mark on the flute surface after polishing. On the other hand too much water content slower the polishing progress which consumes a lot of time to flatten the surface. Therefore, polishing media water content of 30% is recommendable as the most effectives polishing parameter when performing the polishing process to smoothing the drill flute surface.

5.3.2.2 Surface treatment by changing the polishing media injection angle and polishing time

From the previous section, it was revealed that smoothing the flute surface by the treatment under water content of 30% able to reduce and stabilized the cutting force. However, since all of the conditions removes the grinding mark completely, the other objectives of this study which is to investigate the optimal grinding mark conditions on the drill flute surface in order to increase the cutting tool performance is not yet becomes clear. From the part 1 of this study, **Chapter 3** and **Chapter 4**, it was revealed that the polishing characteristics of the polishing media under injection angle 90 deg. is the polishing media process the work surface while maintaining the initial profile shape of before the polishing process[31], [39]. So it is thought that the grinding mark concave and convex shape is preserved after the polishing process of under injection angle 90 deg. In this section, in order to retain the grinding mark on the cutting tool surface, the drill is treated by varying the polishing time from 1 minutes to 3 minutes under polishing media injection angle of 45 deg. and 90 deg.

Results of the observation by AFM are summarized in Figure 5-6. Surface topographies are shown as 3 dimensional views on the left figures and the surface profile measurement results are shown besides them. After the polishing treatment, in the condition of polishing time 1 minutes under injection angle 45 deg., the wave shape are still observable with the reduction in its height and the concave shape became wider. After further polishing treatment until 3 minutes, no more wavy shape are observable where the surface profile flatten with small concave and convex shape on the surface which is left by the abrasive grain during the polishing treatment. On the other hand, in case of polishing treatment under injection angle 90 deg., condition, the wavy shape remain in both polishing time 1 minute and 3 minutes.

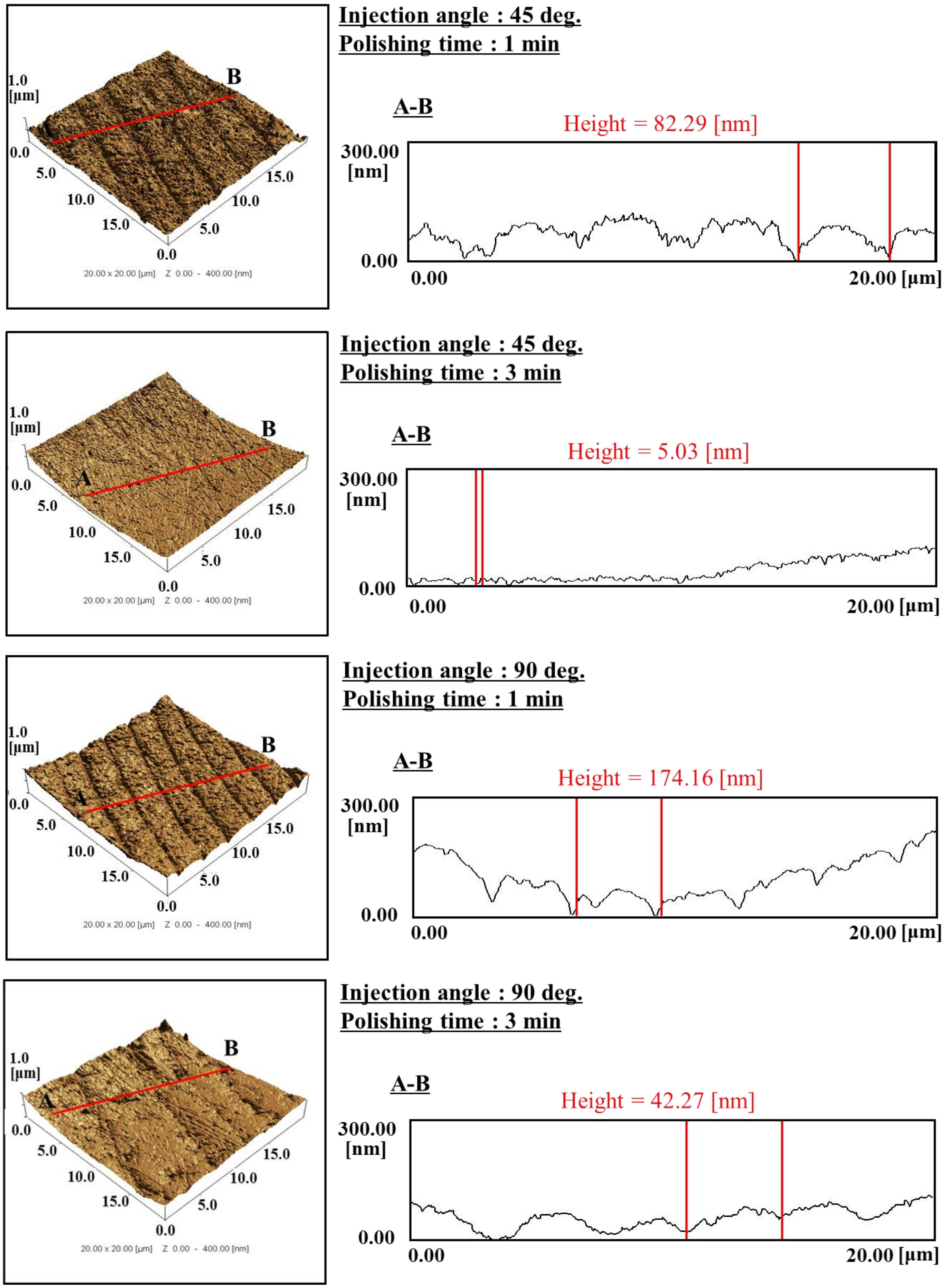


Figure 5-6 AFM surface topography and surface profile after certain polishing time in each water content conditions

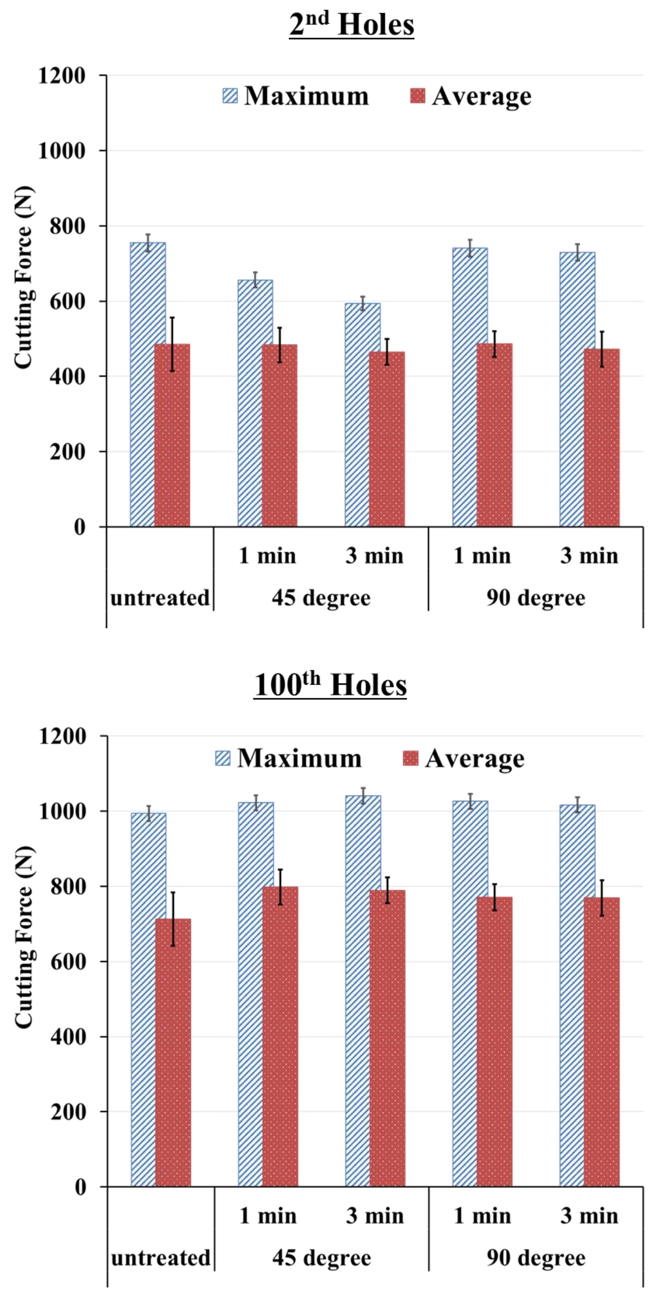


Figure 5-7 Cutting force measurement results.

Moreover in case of 1 minute polishing time condition, the concave shape remain narrow but shallower than the untreated condition as the height decrease. As the polishing treatment increase for 3 minutes, the height decrease further and the concave shape became wider. Therefore from these results, it is confirmed that blast polishing treatment on the drill flute surface are able to control the concave and convex shape of grinding mark property without damaging nor destroying it.

In this section, the cutting test is conducted until 100th holes was conducted to study the influence of these surface properties on the cutting performance by evaluating the cutting force during the drilling process. The cutting force measurement is conducted at the 2nd holes and 100th holes. The results the measurement are shown in Figure 5-7. At the 2nd hole, almost no significant different was observable for the average cutting force neither in the untreated drill nor in the treated drill condition. However, maximum cutting force value for injection angle 45 deg. was found to be lowest compare to other condition. Moreover, this maximum thrust force was found to be lowest at 3 minutes polishing condition, same cutting force result as in the previous section, **section 5.3.2.1**. On the other hand, the cutting force measurement at the 100th hole reveals that the cutting force for the untreated drill shows lowest which is about 15% lower than the average cutting force of those treated with injection angle 45 deg., and about 10% lower of those treated with injection angle 90 deg. In addition, the thrust force for drill treated under injection angle 90 deg. condition is higher compare to the untreated, but slightly lower than the injection angle 45 deg. condition, in both average thrust force and maximum thrust force results.

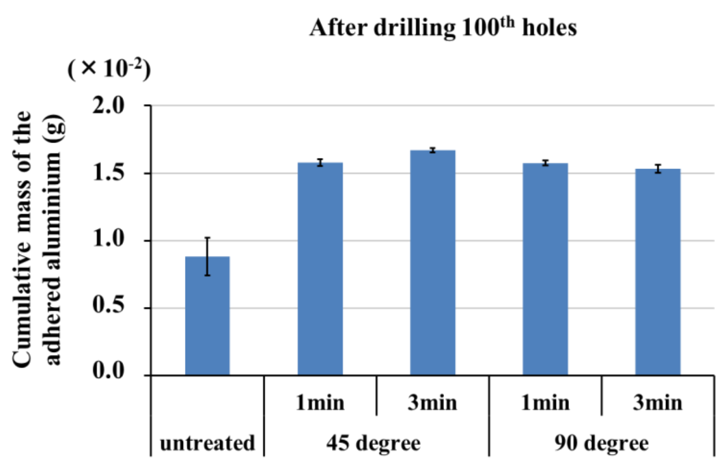


Figure 5-8 Cumulative mass of the adhered aluminium after 100th holes of drilling.

The average cumulative mass of adhered aluminum after drilling 100th hole are shown in Figure 5-8. From this figure, it is observable that there exist a correlation between the thrust force in Figure 5-7 and the adhered aluminum in Figure 5-8. The untreated drill condition for both measurement shows the lowest value compare to those treated drill condition. Moreover the drill treated under injection angle 90 deg.

condition is lower than the injection angle 45 deg. condition for both in the adhered aluminum weight as well as thrust force value.

5.3.3 Optimal surface condition of the drill rake face

5.3.3.1 Observation of the adhesion behavior on the drill rake face

Figure 5-9 shows the observation of the adhesion area of the ADC12 on the rake surface after 100th holes of cutting test. From this figure it is clear that the adhesion only occur on the rake face of the drill. In addition, the treated drill with the smoothest surface condition, which was treated with polishing media under injection angle of 45 deg. for 3 minutes, shows a greater adhesion area. Whereas, the untreated drill with the grinding mark textures on its surface, smaller area of adhesion can be observed and occur only on the rake face that near to the tip of the cutting edge.

Therefore it can be considered that the grinding mark textures on the drill rake surface are able to increase the drill adhesion resistance. Further consideration regarding the function of the grinding mark on the rake face is discuss in the next section.

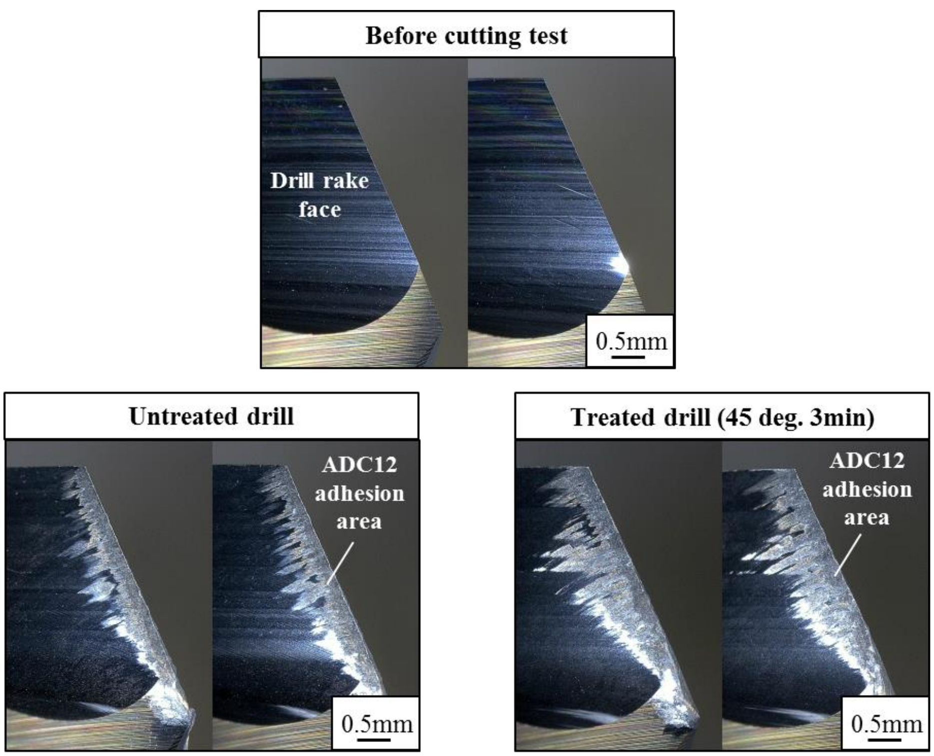


Figure 5-9 Area of adhesion by ADC12 on the drill rake face after 100th holes drilling.

5.3.3.2 Grinding mark function on the drill rake face

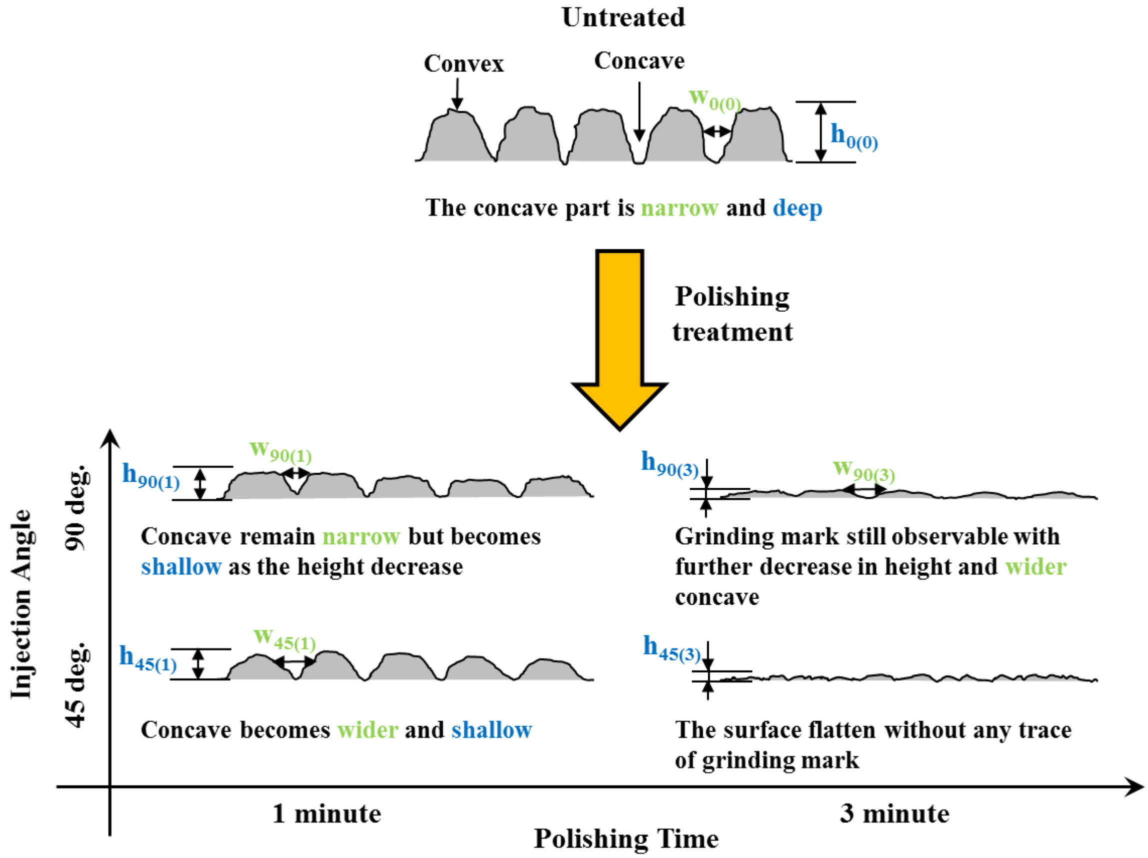


Figure 5-10 Relation of grinding mark convex and concave conditions after the polishing treatment.

The concave part on the grinding mark is thought to function as the lubricant pocket, which provide a place for the lubricant to escape during the severe sliding contact between the tool rake surface and chip. In the case of drill treated under 1 minute treatment, the concave of the $w_{45(1)}$ is wider than $w_{90(1)}$ and also $w_{0(0)}$, but both $w_{45(1)}$ and $w_{90(1)}$ depth are shallower than $w_{0(0)}$ because of the decrease in height, refer to Figure 5-10. Therefore during the drilling process, in the case of $w_{45(1)}$, wider concave area compared to $w_{90(1)}$ makes the aluminum chips easily to enter the concave area and produces chip adhesion inside it. However, with narrower concave area in the case of $w_{0(0)}$ and $w_{90(1)}$, it is sufficient as lubricant pocket for the lubricant to retain in the grooves and prevent chip from adhering inside it. In addition, $w_{0(0)}$ provides better lubricant pocket than $w_{90(1)}$ due to its deeper concave area. At this state, due to chip formation difficulty to enter the concave area, the formation of chip adhesion are believed to be happened only on the top of the convex area, resultantly forming a thin adhesion layer of BUE and Build-Up Layer (BUL)[40], [41].

In the case of 3 minute of polishing treatment, for injection angle 90 deg. the concave becomes wider, $w_{90(3)} > w_{90(1)}$, and its height further decrease. In this case, the lubricant pocket still exists because the grinding mark groove are still observable, however it is believed that this pocket is not sufficient for the lubricant to retain inside it during drilling. In contrary, for injection angle 45 deg., it was found that at the 2nd hole, the maximum cutting force value was the lowest compare to other conditions. The reason of this is because of its smooth flat surface. The friction at the interface between the tool and chip is lower which result into lower cutting force value initially. However, at this state, the BUE already exists and gradually a thin BUL layer formed on the surface. After further drilling, with no lubricant pocket for the lubricant to retain, a larger area of the tool surface is exposed to the chip at the interface. Thus, the BUL increase thicker which resulted to the increase of cutting force[42], [43].

As conclusion, these results indicate that grinding mark micro texture improves the adhesion resistance by reducing the contact area between the tool rake face and chip during the cutting process and also as the lubricant pocket which provide reservoir for the lubricant to escape by the severe sliding contact between the tool and chip. In addition, too much polishing on the tool surface may remove these textures and resultantly worsen the tool performance.

5.3.3.3 Relation of grinding mark and chip flow direction

Figure 5-11 shows the evaluation result between the direction of the grinding mark and the flow direction of chip. From this figure, it was found that the chip flow direction is at approximately 45 deg. with the direction of the grinding mark. It is thought that if the direction of the grinding mark is vertically with the chip flow direction, the adhesion resistance on the rake face can further be improved and lower cutting force value can be obtained. In the next chapter, **Chapter 6**, further study regarding the effect of grinding mark direction to the chip flow direction is conducted.

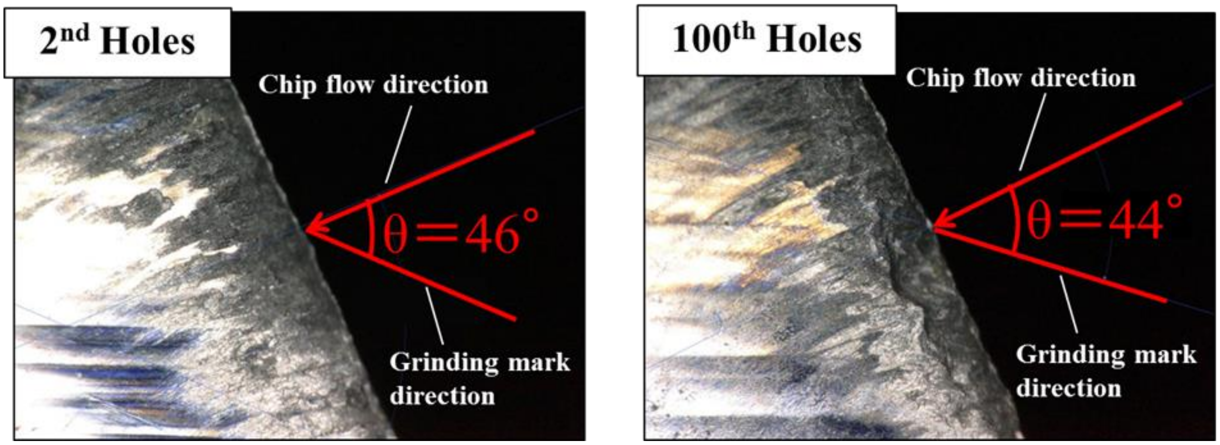


Figure 5-11 Relation of grinding mark and chip flow direction

5.3.4 <u>Optimal surface condition for the drill guide flute</u>

In the previous section it is clear that by leaving the grinding mark on the drill flute surface without any polishing treatment successfully increase the tool performance by reducing the cutting force and also increase the adhesion resistance on the rake face. However, a studies have reported that mirror polished drill flute surface has able to reduces the cutting force during cutting[17]. This report contradict the obtained results in this experiment. To further understand the cutting force behavior with the depth of drilling during the drilling process, we observe the cutting force pulse with the relation of drilling time and drilling depth. The relations is shown in Figure 5-12. The cutting force pulse in this figure is simplified by the moving average to have a better view of the relation between drilling time and drilling depth.

From this figure, it is observable that for the untreated drill there are three stages (shown in the figure with circle number) of the cutting force behavior with relation in the depth of drilling. On the first stage, initial drilling depth, within the depth of 10 mm, a stable cutting force line can be observed. It is thought that at this drilling time, the lubricant oil sufficiently reached the rake face and the grinding mark are able to function properly by providing the storage for the lubricant to escape. However, on the second stage where the depth of drilling is within 10 mm to 16 mm, a sudden rise in the cutting force can be observed. It is thought that at these depth, the supplies of lubricant to the rake face slowly becomes insufficient which prevent the grinding mark to function properly and even worsen the chip evacuation thru the guide flute.

Finally on the third stage, where the drilling depth is within 16 mm to 28 mm, the cutting force stop rising and stabilized. At these depth, more crucial working environment for the rake face where the lubricant supply is extremely low. Moreover, the chip evacuation along the guide flute is also worsen. However, as the lubricant is still retain inside the concave part of the grinding mark on the rake face, the cutting force for the untreated drill is reduced slightly lower than the drill with the smoothest flute surface, treated with polishing media under injection angle 45 deg. for 3 minutes, hereafter is referred as all flute (A.F) polished drill.

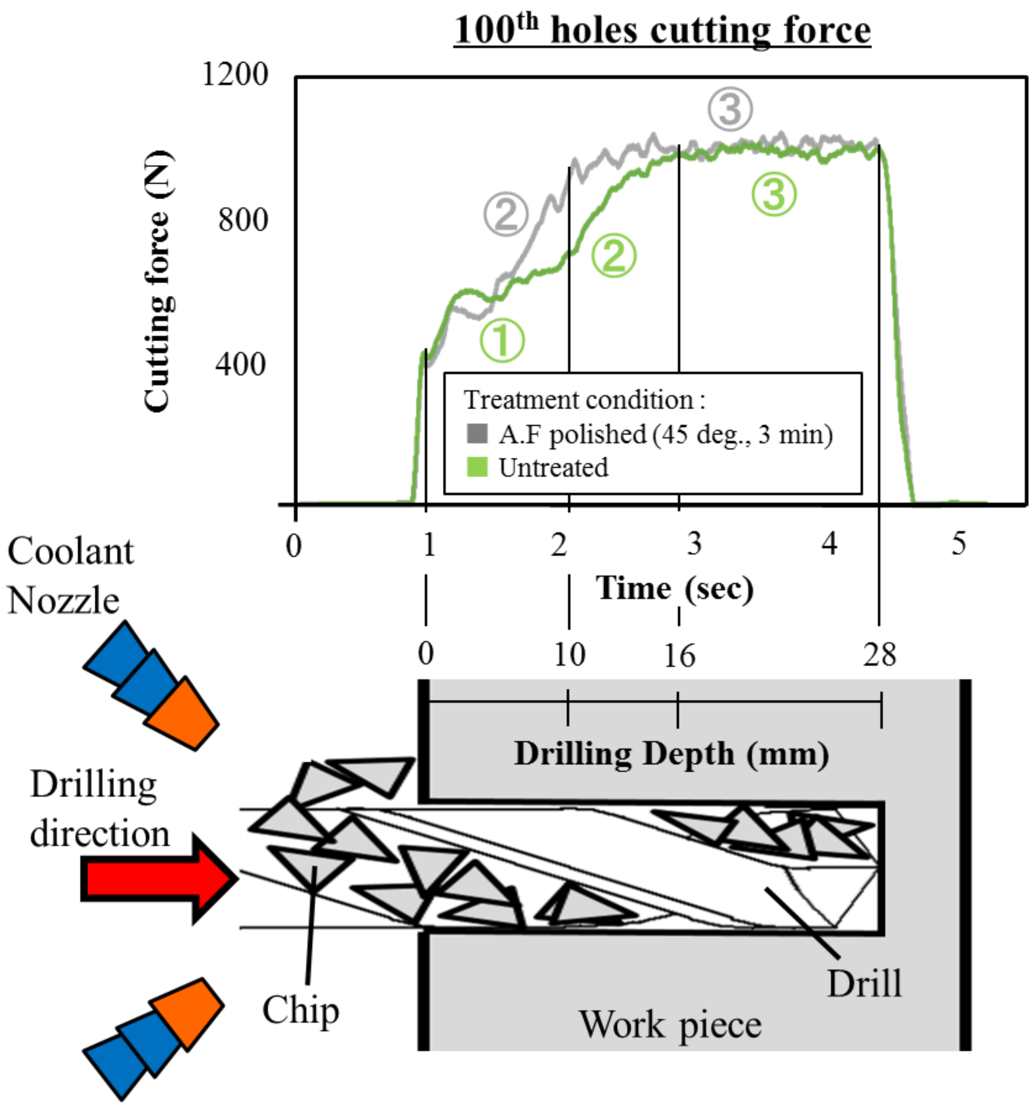


Figure 5-12 Cutting force relation with the drilling time and drilling depth for two type of drill conditions.

On the other hand, for the A.F polished drill, the sudden rise in the cutting force can be observed shortly after the drill touches the work piece. Therefore it is thought that there are no first stage for the A.F polished drill. A sudden rise shortly after starts of drilling indicate that the cutting force for A.F polished drill goes directly to the second's stage. In addition, when the drilling depth exceed 10 mm, the cutting force stop rising and stabilized until the end of drilling, the third stage. For the A.F polished drill condition, although the lubricant flow and sufficiently reached the rake face, due to no grinding mark texture on its rake face, the lubricant film on the rake face is removed by severed sliding contact between the tool surface and the chip which increase the contact area at the interface and provide a friendly conditions for the formation of BUE and further the formation of BUL. The BUL layer continues to grow thicker and resulted to the rise of the cutting force.

From these observation, it can be considered that the surface condition of the drill guide flute also influence in the cutting performance. The guide flute function by providing a path for the lubricant oil to flow inside the hole and enable the chip together with the lubricant to evacuate the hole during the drilling process. The tranquility of chip evacuation and high lubricant fluidity is essential in maintaining a stable cutting force during drilling. The interruption of these two factors causes the cutting force to rise.

While at the initial drilling depth the cutting force is successfully decrease, however when the depth of drilling is increase, due to disturbance of flow along the guide flute, the cutting force rise abruptly. Therefore, it is thought that by smoothing the guide flute surface it can further prevent the sudden rise in the cutting force by providing less friction between the guide flute surface and the chip as well as allowing the lubricant to flow smoothly through the guide flute groove. For this purpose, an experiment of changing the range of the polishing treatment throughout the guide flute groove is conducted. Fig 5-13 shows the polishing range of the guide flute surface in this experiment. The polishing parameters of water content of 30%, injection angle of 45 deg., injection speed of 59.5 m/s, and polishing time of 3 minutes is used for this treatment as it has been proven in previous section to successfully removes the grinding mark and smoothest the surface efficiently. Moreover, the range of 16 mm from the cutting edge is left untreated because within this depth of drilling the cutting force reached its peaked and stabilized until the end of drilling. The cutting test is conducted until 100th holes and cutting condition is shown in Table 5-2, same as the previous test.

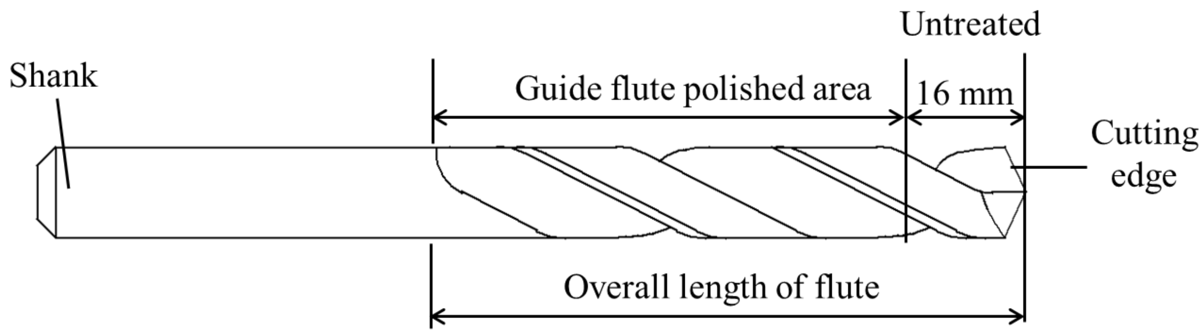


Figure 5-13 Polished area in the experiment of changing the range of treatment.

5.3.4.1 <u>Influence of changing the guide flute polishing range on the cutting performance</u>

Figure 5-14 shows the cutting force measurement result of drilling 2nd holes and 100th holes for the untreated drill and the drill with only the guide flute surface is polished. Hereafter the only guide flute polished drill will be referred as G.F polished drill. From this measurement results, it clear that compare to the untreated drill, the G.F polished drill successfully reduced both the average cutting force and maximum cutting force to much more lower value. Therefore it is clear that the optimal surface condition for the guide flute should be without the grinding mark which is the smooth polished surface. It is thought that the smooth polished guide flute surface enables the chip and lubricant oil to flow smoothly throughout the guide flute groove by reducing the friction at the interface. Thus effectively prevent the chip clogging and insufficient supply of lubricant to the rake face when the drilling goes deeper into the work piece.

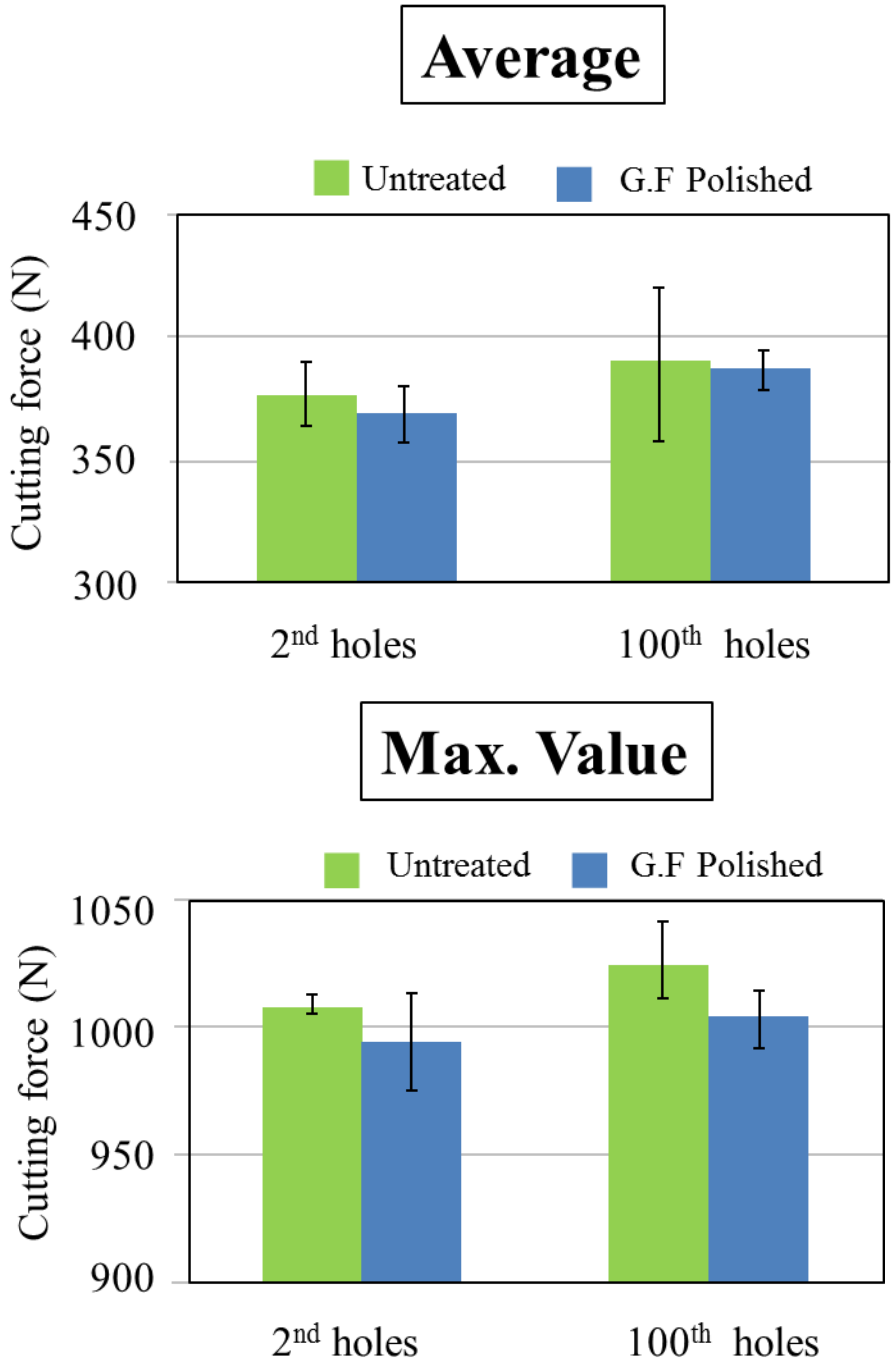


Figure 5-14 Comparison of average and maximum cutting force value for the untreated and G.F polished drill.

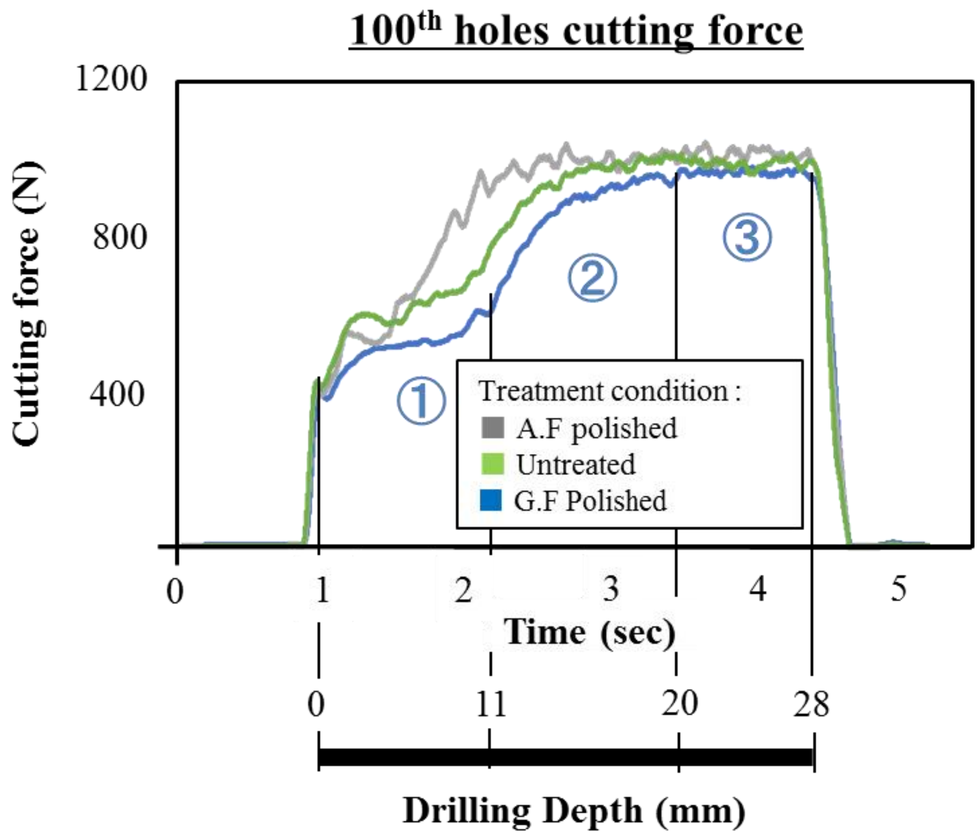


Figure 5-15 Cutting force relation with the drilling time and drilling depth for three type of drill conditions.

Figure 5-15 shows the relation of the cutting force line for the untreated drill and G.F polished drill in comparison with the drilling time and drilling depth. From this figure, it is observable that at the first stage of drilling depth, for the G.F polished drill, the cutting force remain stable and lower for longer time until 11 mm of drilling depth before entering the second stage where the cutting force starts to rise gradually. When entering the second stage of drilling depth, the cutting force start to rise gradually. However, when compare to other drill conditions, it rises slightly slower and takes longer times to reached peak before stabilized. Finally, at the third stage, when the drilling depth is within 20 mm to 28 mm, the cutting force stop rising and stay stable until the end of drilling. Additionally, it stabilized slightly lower than other drill conditions. Therefore it can be concluded that the G.F polished drill can further lower the cutting force and also delaying the sudden rise of the cutting force at the first and second stage of drilling depth.

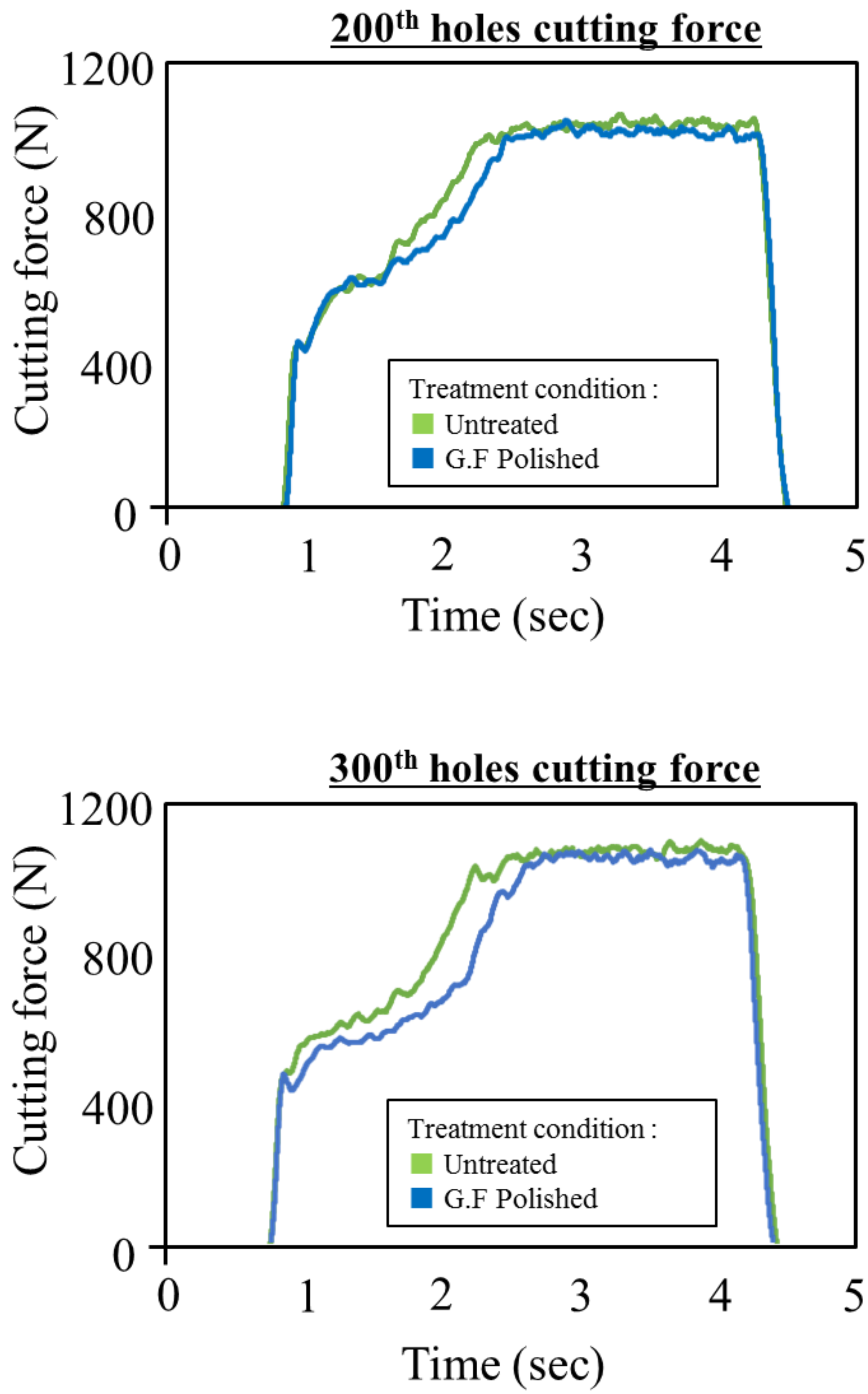


Figure 5-16 Cutting force measurement during drilling the 200th holes and 300th holes.

To further confirm the effect of G.F polished, the cutting test is extended to until 300th holes of drilling. The cutting force measurement is conducted during drilling the 200th holes and 300th holes. Result of cutting force measurement in each holes are shown in Figure 5-16. From this figure it is confirm that the G.F polished drill is still functioning in lowering the cutting force and able to delay the rise of the cutting force.

As the conclusion, the optimal surface condition for the drill guide flute should be polished into mirror surface condition because it was found to be effectives in order to maintain lower cutting force. This is because mirror polished surface reduces the friction along the guide flute that improve the fluidity of the lubricant oil. As a result the lubricant is able to flow inside the cutting hole to reach until the rake face and allowing the generated chip to easily discharge together with the lubricant

5.4. <u>Summary</u>

In this chapter, the flute surface of cutting tools were treated by blast polishing with several selected parameters in order to investigate the optimal surface property in order to increase the cutting tool performance by reducing the cutting force and increase it adhesion resistance. The results are summarized as followings:

1. Result of treatment the cutting tool with blast polishing media with different water content conditions shows many scratch mark on the surface polished with water content of 10%. In addition, these scratch mark is less observable on the surface polished with higher water content conditions. However a very slow polishing progress for the surface polished with water content of 50% where the grinding mark shape is slightly appear on the surface profile. Therefore it is better to use water content of 30% to removes the grinding mark structure and attained smooth polished surface effectively.
2. Regarding the injection angle and polishing time influence to the grinding mark property, it was revealed that the grinding mark heights reduces proportionally with the time of treatment. However, a different appearance in grinding mark concave and convex shape after polishing under injection angle 45 deg. and 90 deg. In case of injection angle 45 deg., the grinding mark concave becomes wider and

as the treatment time continues, the surface flattens. In contrary, treatment under injection angle 90 deg. flattens the upper convex shape and at the same time keeps the concave shape narrow.

3. A correlation exists between the cutting force measurement and the adhered aluminum results after drilling 100th hole. The untreated drill for both measurement shows the lowest value compare to those treated drill condition. Additionally, the drill treated under injection angle 90 deg. condition is higher compare to the untreated, but slightly lower than the injection angle 45 deg. condition, both in the cutting force and adhered aluminum.

4. It is clear that the untreated drill shows better adhesion resistance and able to reduce the thrust force. The reason for this is due to the influence of grinding mark texture on the rake face. Grinding mark textures provides the lubricant pocket which is the escape holes for the lubricant to retained inside it and reducing the contact are between the interface of tool and chip thus preventing the formation of adhesion. The untreated drill have deeper and narrower concave parts which provides better lubricant pocket.
5. It can be conclude that the grinding mark texture is the optimal surface condition for the rake face.
6. It was revealed that there are three stages of drilling depth when comparing it with the drilling time. At the initial drilling depth, the cutting force is successfully reduces by the untreated drill condition in comparison with the A.F polished drill. When the drilling goes deeper, the cutting force rise suddenly and reached the peaked with slightly lower than the A.F polished drill. It is thought that the condition of guide flute surface highly effected the rise of the cutting force.
7. The study of the changing the polishing range of the guide flute, it was revealed that the G.F polished drill can further lower the cutting force in both average and maximum value. In addition, the G.F polished drill effectively delayed the rise of the cutting force at the first and second stage of drilling depth and are able to function even after further cutting test was conducted.
8. It can be conclude that the optimal surface condition for the guide flute should be mirror polished surface. This is because the mirror polished surface reduces the friction along the guide flute that

improve the fluidity of the lubricant oil. As a result the lubricant is able to flow inside the cutting hole to reach until the rake face and allowing the generated chip to easily discharge together with the lubricant.

6. Effects of grinding mark textures to the adhesion behavior of aluminum alloy

6.1. Introduction

In the previous chapter, the state of grinding mark was found to affect the cutting performance. Particularly, since the cutting performance is changed when the number of drilling is increased, it is thought this was due to the change in the friction condition on the tool flute surface causes by the adhesion of the aluminum alloy on the surface. Furthermore, it has been revealed in the previous chapter that the optimal surface condition for the rake face should be left with the grinding mark texture. These texture helps to reduces the cutting force and increase the adhesion resistance by providing a space for the lubricant to escape during the severe sliding contact with the chip as well as reducing the real contact area at the interface.

To further prove this theory, in this section, a friction test is conducted by sliding the work piece by certain load on the carbide substrate surface. The surface of the carbide substrate is pretreated by surface grinding machine to replicate the grinding mark on the drill rake surface. Then it is treated by blast polishing process for several polishing time until reached the mirror polished surface condition. The friction coefficient during the sliding test as well as the amount of adhesion on the surface after the test is investigated.

6.2. Experimental conditions

Table 6-1 shows the treatment conditions on the carbide substrate surface. In order to investigate the influence of grinding mark when changing condition of the convex and concave shape, the carbide substrate surface is treated by blast polishing process for several polishing time which 10 seconds, 30 seconds and finally 90 seconds, until the grinding mark textures is completely removes and the surface turn to mirror polished surface state. The other polishing parameters such as the injection angle, injection speed and water content was set to it most effective polishing ability.

The condition of the friction test is as shown in Table 6-2, friction test under dry conditions, and Table 6-3, friction test under wet conditions. The test direction is linear reciprocating and conducted vertical and parallel with the grinding mark direction. The lubricant used under wet condition is the FGE360, which is the same lubricant that has been used for the cutting test in the previous chapter.

Table 6-1 Injection condition for researching effect on cutting effect

Injection condition	Injection angle (deg.)	45
	Polishing time (s)	10,30,90
	Injection speed (m/s)	59.5
	Injection quantity (g/s)	36
	Nozzle width (mm)	5
	Injection distance (mm)	20
Polishing media	Multi-Cone (g)	1000
	Multi-Powder #3000 (g)	30
	Water content (%)	30

Table 6-2 Condition of friction test in dry condition.

Pin	ADC12
Plate	Cemented carbide
Test direction	Linear reciprocating
Load (N)	4.9
Test speed (mm/s)	8.5
Test distance (mm)	3
Number of reciprocating	50

Table 6-3 Condition of friction test in wet condition.

Block	Cemented carbide
Plate	ADC12
Test direction	Linear reciprocating
Load (N)	9.8
Test speed (mm/s)	8.5
Test distance (mm)	50
Number of reciprocating	50
Lubricant	FGE360

6.3. Results and discussions

6.3.1 Friction test under dry condition

6.3.1.1 Surface observation before the friction test

A summary of the cemented carbide surface state subjected to the blast polishing treatment is shown in Figure 6-1. The observation results shows that the grinding mark that exist on the cemented carbide surface before the polishing process is removes gradually in accordance with the increase of polishing time. Particularly, it can observed that the grinding mark textures on the process surface is completely disappear and the surface turns into smooth flat surface after 90 seconds of polishing process. Figure 6-2 shows the surface roughness measurement of the process surface before and after each polishing process. From this results, it is clear that the surface roughness, Ra, and the maximum height of the grinding mark, Rz decreases after the polishing process and continue to decline as the polishing time increase. Especially for the process surface polished until 90 seconds, the surface roughness has been reduced to about 1/3 of the height of the grinding mark before the polishing process.

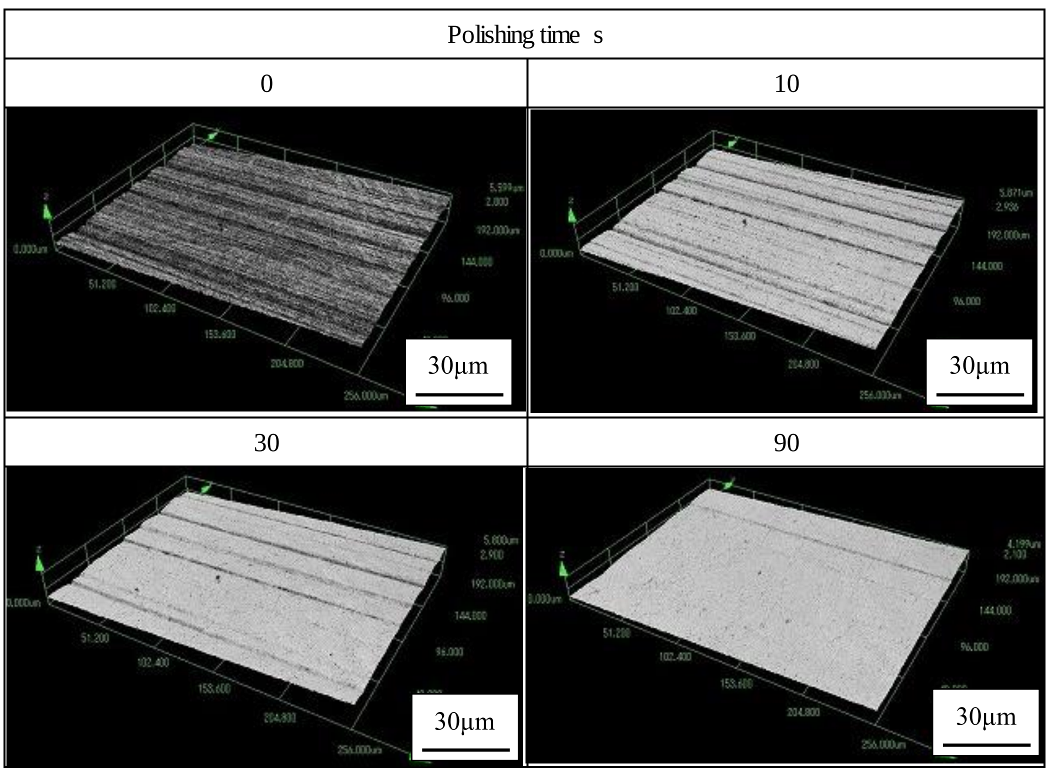


Figure 6-1 Condition of friction test in wet condition.

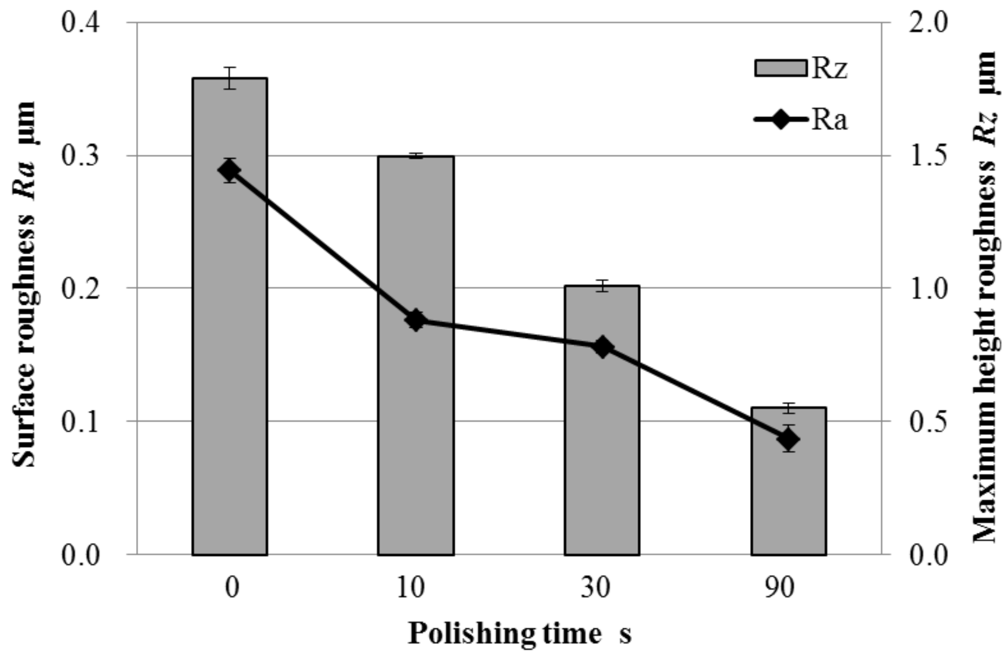


Figure 6-2 Condition of friction test in wet condition.

6.3.1.2 <u>Measurement of the amount of adhesion</u>

The amount of adhesion was measured from the weight difference between the cemented carbide samples before and after the friction test. The result of measurement are shown in Fig 6-3. From the measurement results it is observable that the minimum adhesion amount was obtained on the surface polished with 10 seconds of polishing treatment where the test direction is vertical with the grinding mark direction. The second lowest adhesion amount was obtained on the surface without any polishing treatment and also the test direction is vertical with the grinding mark direction. On the other hand, the highest adhesion amount was obtained on the surface where the test direction is parallel with the grinding mark direction, regardless of the surface treatment condition. Under the vertical test direction, due to the existence of the grinding mark texture on the surface, with its convex and concave shape, during the test the pin only touches the top of the convex portion which reduce the contact area between the pin and the process surface.

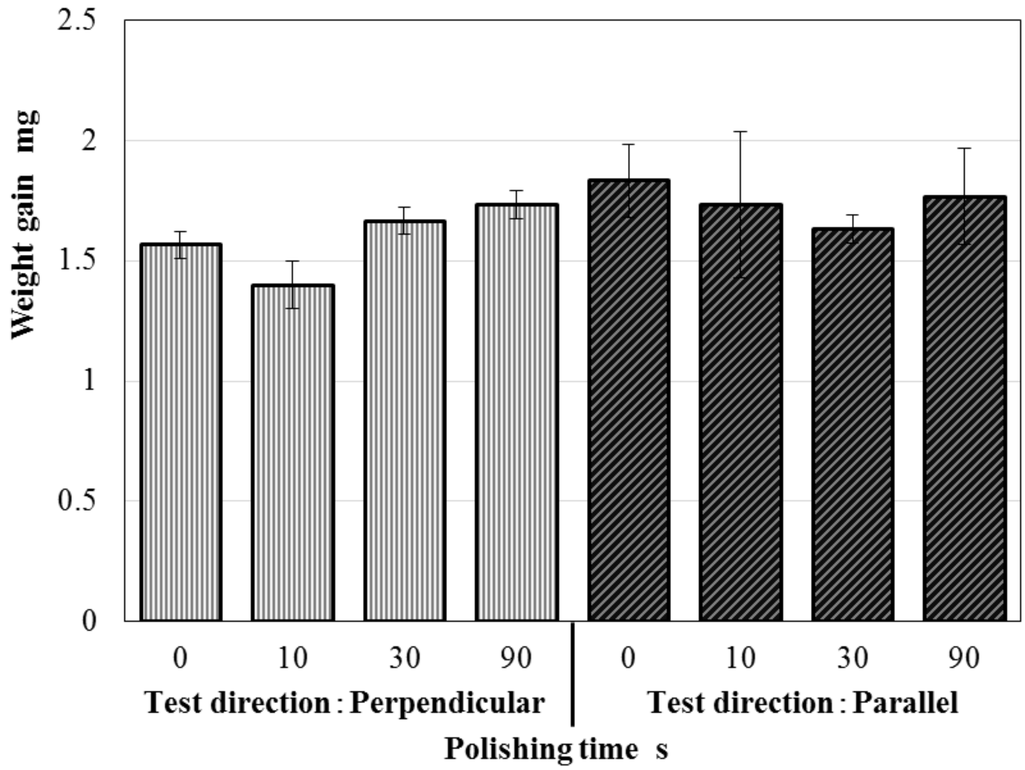


Figure 6-3 Weight gain after friction test.

To further understand the adhesion behavior on the process surface, an observation by laser microscope was conducted on the cemented carbide surface after the friction test. Result of observation are shown in Figure 6-4. The results shows that the ADC12 is attached throughout the surface of cemented carbide substrate particularly when the test direction is parallel with the grinding mark direction. On the other hand, under vertical direction with the grinding mark, it was observed that the ADC12 only adhered on the top of the convex portion of the grinding mark.

From these fact, during the friction test under vertical test direction, it is thought that due to the pin only making contact with the convex portion of the grinding mark texture, the contact area between the interfaces is reduces. As a results, lowest amount of adhesion was obtained on the surface of carbide substrate with the existence of the grinding mark texture. In addition, in the polishing treatment under 90 seconds conditions, due to the grinding mark textures was completely removed, the contact area between the pin and the surface increased. Therefore, greater amount of adhesion by ADC12 was obtained on the surface regardless the direction of the friction test.

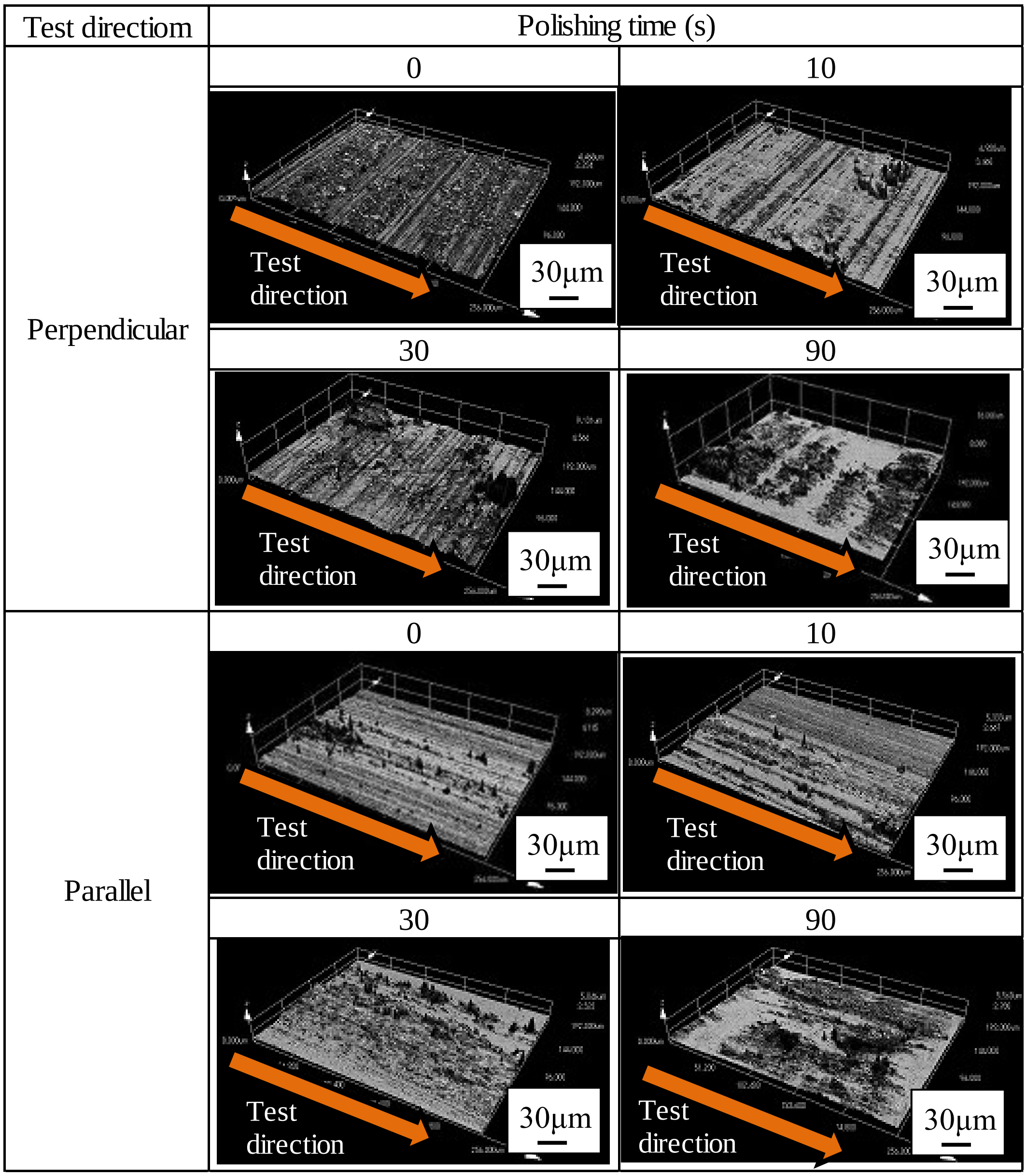


Figure 6-4 Observation result of carbide surface after friction test in dry condition.

6.3.1.3 <u>Friction coefficient measurement results</u>

The results of friction coefficient during the friction test are shown in the Figure 6-5. The measurement are conducted at the initial friction test which corresponding to the reciprocating number of 1-5 times, and at the final friction test which correspondence to the reciprocating number of 46-50 times. The measurement results shows that during the initial friction test, the friction coefficient shows a tendency to decrease when the polishing time on the process surface is increase, both in the vertical and parallel test direction. However, when the reciprocating number increase finally until 46 to 50 times, the friction coefficient under vertical direction result shows completely the opposite tendency where the friction coefficient becomes larger when the polishing time on the process surface increase and the surface with the grinding mark existence on it shows lower value. Moreover, under parallel test direction, almost no significant different was observed.

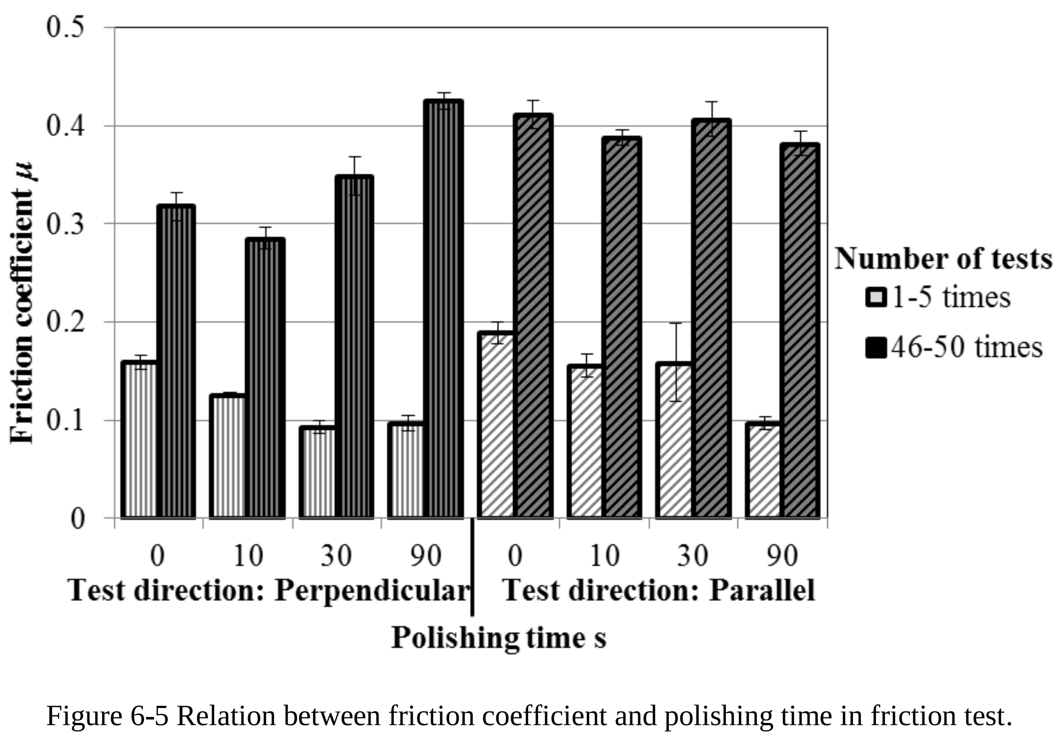


Figure 6-5 Relation between friction coefficient and polishing time in friction test.

There a correlation between the amounts of adhesions in the previous section with the result of the friction coefficient. As indicate in the previous section, the surface without grinding mark texture that is treated with 90 seconds of polishing time, although at the initial friction test lower friction coefficient result, however, due to large contact area between the pin and the surface causes the adhesion layer on the surface to grows thicker in accordance to the increase of reciprocation test. Thus, the surface state gradually worsen by this adhesion resulted to the increase of friction coefficient on the surface. In particular, when the test direction is parallel with the direction of grinding mark, regardless of the polishing treatment condition, it is considered that due to the ADC12 continuously deposited on the surface during the test, it worsen the surface condition and eventually increase the friction coefficient. On the other hand, when the test direction is vertical with the direction of the grinding mark, because the adhesion only occur on the convex portion of the grinding mark, the surface state with the grinding mark condition did not change significantly compare to the surface without the grinding mark. Although the friction coefficient increase, it did not increase suddenly.

From the above results, it can be concluded that the adhesion resistance is increased when the test direction is vertical with the grinding mark direction. Because under these condition, a smaller contact area is acquired at the interface of those two materials. As a results, the amount of adhesion can be reduces as well as minimized the friction coefficient at the interface.

6.3.2 <u>Friction test under wet condition</u>

6.3.2.1 <u>Surface observation before the friction test</u>

Although in the previous section the effect of grinding mark to the friction coefficient and the adhesion behavior had becomes clear, but the test was conducted under dry condition. In the sectors of machining the aluminum alloy in the industries, almost all the machining is conducted under wet condition which applies lubricating oil in the machining process. This is because dry machining aluminum of alloy has proven difficult due to aluminum's adhesion to the drill. The chip that adhere to the drill create obstacles to chip evacuation through drill guide flute. Such chip clogging often results in drill rapid failure[44].

Therefore it is also important to conduct the friction test with lubricant evaluate the effect of grinding mark performance under wet condition with the relation to the friction coefficient and the adhesion behavior.

From the previous section, it is clear that a large different was observed in the friction coefficient and the adhesion behavior between the surface with the grinding mark texture and the smooth surface without the existence of grinding mark. For this reason, in this section only two surface condition is investigated. Figure 6-6 shows the surface observation result of the cemented carbide substrate after the pretreatment with grinding machine and the surface after the polishing. For the polished surface shown in the figure, because the blast polishing is the injection type of polishing process, it is impossible to polish the entire surface uniformly. Therefore, in this experiment a polishing by buffing is applied, which completely removes the grinding mark texture as well as to obtain the surface roughness equivalent to the surface roughness polished by blast polishing method for 90 seconds in the previous section.

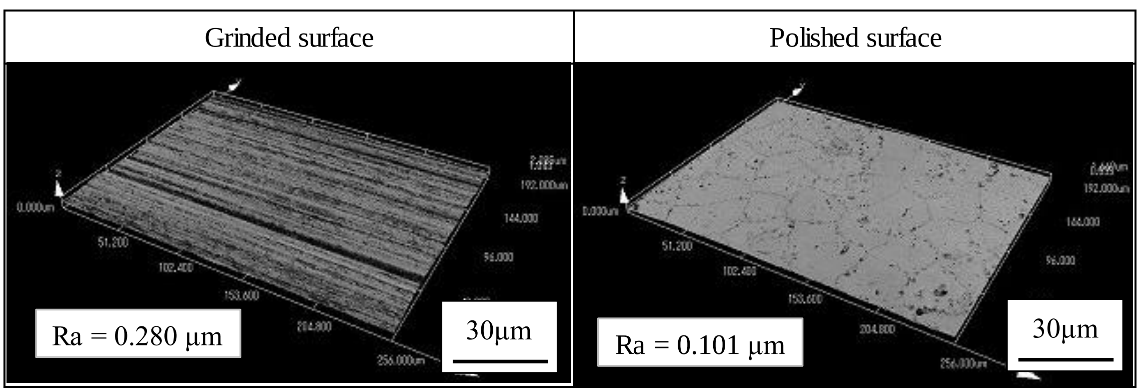


Figure 6-6 Observation result of carbide surface before friction test.

6.3.2.2 <u>Friction coefficient measurement result</u>

Figure 6-7 shows the result of friction coefficient measurement during the friction test. The measurement method as well as the test direction is in the same method as in the dry conditions. As for the result, at the initial friction test, reciprocating number 1-5, almost no significant different was observable between the friction coefficient values in each surface conditions. However, when the reciprocating number reaches 46-50, which is the end of the test, the polished surface shows an increment in the friction coefficient value.

On the other hand, the surface with the grinding mark texture on the surface, the friction coefficient value decrease lower than the initial friction test result. Particularly under vertical test direction, the friction coefficient decrease to the lowest. From this result, it can be considered that during the friction test, due to severe sliding between the interfaces, the lubricant film on the carbide surface is forces into the concave portion of the grinding mark and retain inside it. This act reduces the contact area between those two sliding materials and resulted to the reduction of the friction coefficient. For the polished surface, with no lubricant pocket on its surface, the carbide surface becomes more vulnerable without protection by the lubricant film due to it completely removed during the sliding. This action increased the contact area at the interface and created a friendly environment for the adhesion to form on the surface. As the sliding test is carry on, the adhesion layer on the surface keeps growing and becomes thicker hence the friction coefficient increase. However, the amount of adhesion by ADC12 on the carbide surface, which is the different in the weight before and after the friction test cannot be evaluate due to a very small adhesion on the surface.

To further study the adhesion behavior on the carbide surface, an observation by laser microscope is conducted. The observation result is shown in Figure 6-8. From this figure, it was observed that in any surface conditions the ADC12, the portions in black color was attached on the surface. However, it is clear that a greater area of adhesion by ADC12 can be observed on the polished surface of the cemented carbide. Whereas, for the surface with grinding mark textures, under vertical test condition, the ADC12 adhesion was observed to only attached on the top of the grinding mark textures. From these observation, it is proved that the grinding mark concave portion function as the reservoir for the lubricant oil. Therefore even the test number is increase, the friction coefficient did not increase due to the lubricant retain inside the concave and preventing the adhesion to growing further. As compared with the vertical test condition, under parallel test condition, in accordance with the increase of test number, the concave portion is filled by deposition of ADC12 causes to the reduction of depth of the concave portion and resulted to the increased of friction coefficient.

From the above results, it can be considered that it is possible to reduce the friction coefficient of the surface when the grinding mark is vertical with the test direction due to the lubricant oil accumulated in the concave portion of the grinding mark to reducing the area of contact between those two sliding material and preventing the adhesion from increase.

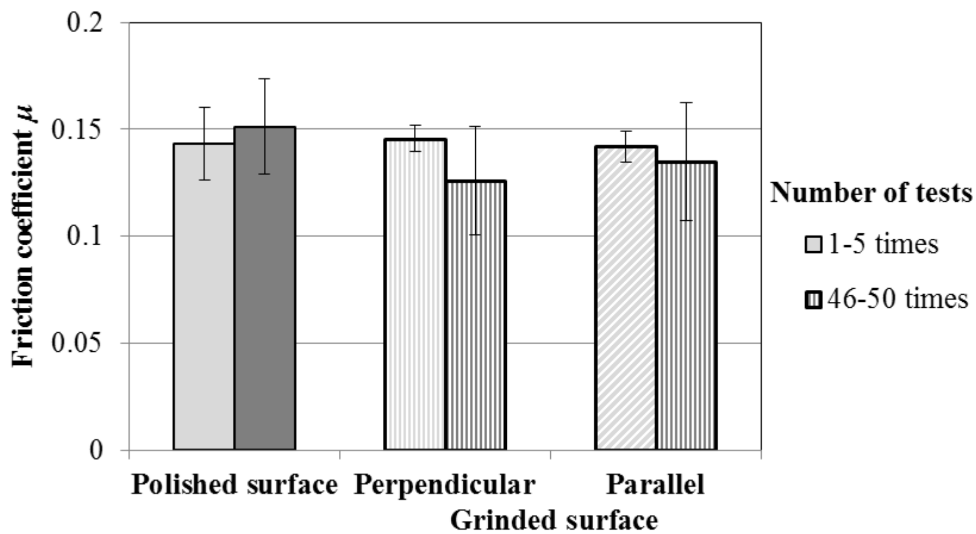


Figure 6-7 Relation between friction coefficient and surface condition in friction test.

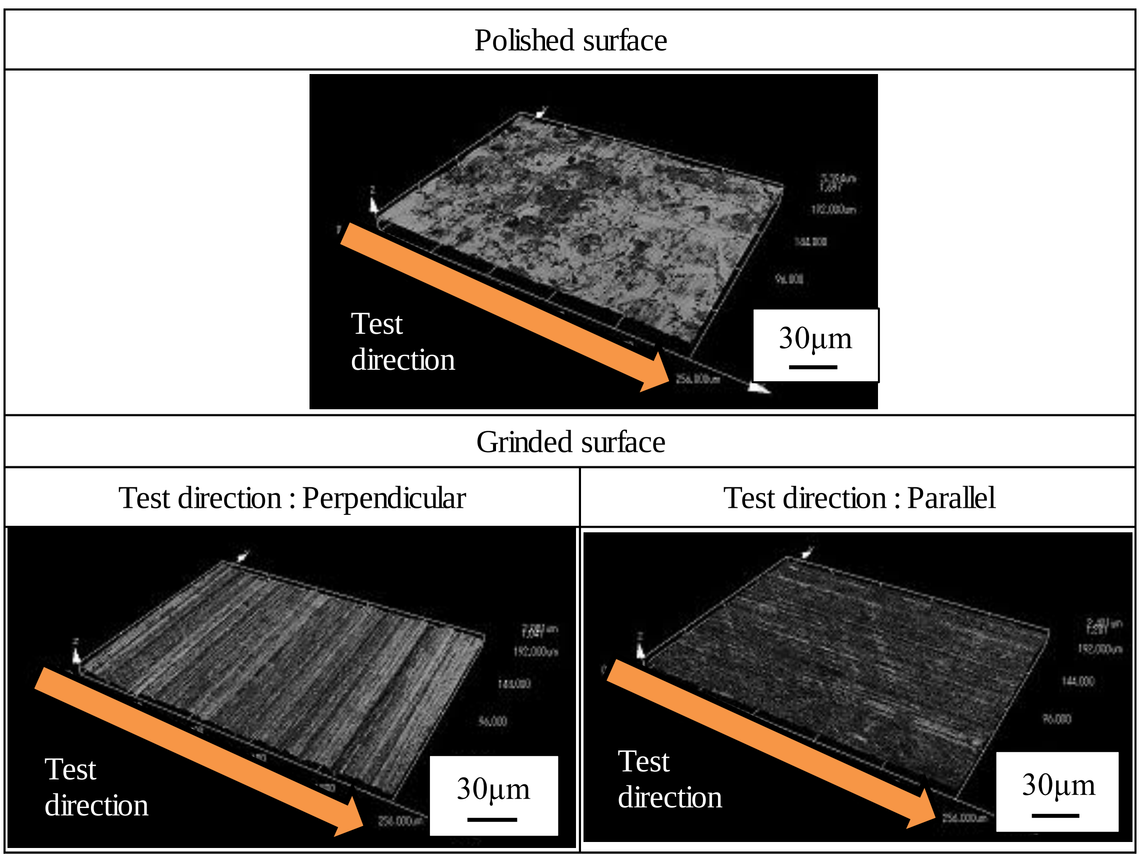


Figure 6-8 Observation result of carbide surface after friction test in wet condition.

6.4. Summary

In this chapter, the friction test is conducted on the surface of cemented carbide with and without grinding mark texture been implemented on it in order to evaluate the grinding mark function on the surface to its relations with the friction coefficient and the adhesion behavior. The results are summarized as followings:

1. For the friction test under dry condition, the amount of adhesion was found to be smaller when the friction test direction is vertically with the grinding mark direction.
2. Results of the surface observation after the friction test revealed that larger area of ADC12 is attached on the surface when the test direction is parallel with the direction of the grinding mark as well as on the surface polished for 90 seconds. Whereas, when the test direction is vertical with the grinding mark direction, the ADC12 is found to mainly attach on the convex portion of the grinding mark textures.
3. Results of friction coefficient during the test revealed that at the initial test number, the friction coefficient showed a tendency to decrease on the most polished surface. However, as the number of test increase, due to the increase of adhesion on the surface, the surface condition worsen and the friction coefficient quickly increased and becomes the highest, while the surface with grinding mark textures conducted under vertical test direction shows the lowest value.
4. In dry conditions, for the surface with grinding mark textures with vertical test direction conditions, it is considered that only the convex portion is in contact with the ADC12 during the sliding. Therefore it reduces the area of adhesion and enable to suppress an increase in the frictional resistance.
5. As for the wet conditions, for the surface with grinding mark textures, it was found that the friction coefficient is increase immediately after the start of the test and showed a tendency to decrease as the number of test is increase. This is because as the number of test is increase, the lubricant oil gradually becomes acquainted with the surface conditions by accumulation in the concave portion of the grinding mark thus improved the friction resistance.
6. Results of observation on the surface after the friction test revealed that the adhesion amount is lesser

when compare with dry conditions especially on the surface with the grinding mark textures. It indicates that the function of grinding mark is fully maximize under wet conditions.

7. This is because, under wet conditions, particularly under vertical test direction, the lubricant oil accumulates the concave portion of the grinding mark and reduces the area of contact between the surface and the work piece thus improves the friction coefficient and prevent the adhesion to grow. Furthermore as long as the concave portion is not filled by deposition of work piece material by adhesion, the friction coefficient is considered less likely to worsen.

7. Conclusions

7.1. <u>General conclusion</u>

In this present thesis, two main issues are focused. The one is to reveal the polishing mechanism of the blast polishing process and the second is to investigate the influences of this process to the cutting tool performance by surface modification. As the first issue of this study, which is regarding the polishing mechanism of the blast polishing process two main point is investigated which is the “**Effect of several factors in blast polishing process on surface condition of cemented carbide**” explained in **Chapter 3**, and “**Polishing mechanism on cemented carbide substrate by blast polishing process**” that is explained in **Chapter 4**. For the second issue, it was regarding the surface modification method on cutting tool surface. There are two critical point regarding this method is investigated which is a method by mirror polished the surface and a method by surface texturing. A complete contradictory method but both has reported to improve the cutting tool performance. Therefore it is important to investigate both method because it is believed that a different surface condition is required for the specific part of the cutting tool because each particular parts has its own particular role and function independently. And, by the combination of these parts finally the cutting tool performance can be increase. **Chapter 5**, entitled “**Study on optimal surface property of carbide drill for aluminum alloy cutting**” investigated these points. Then the consideration regarding the grinding mark function explained in this chapter is further investigated and evidence is revealed in **Chapter 6** which is entitle “**Effects of grinding mark texture to the adhesion behavior of aluminum alloy**”. Following is the conclusions of the results obtained in this study.

In **Chapter 3**, entitled “**Effect of several factors in blast polishing process on surface condition of cemented carbide**”, the factors of polishing media injection speed, injection angle and water content was investigated to study the influence of these factors on surface condition of cemented carbide substrate by the relations of polishing time and surface roughness value.

As a result, in the condition of injection speed is below 12.3 m/s, the obtained surface roughness measurement values revealed that the surface roughness shows a tendency to monotonously decrease with the lapse of polishing time without saturated. However, in the condition when the polishing media injection speed is 12.3 m/s or more, the surface roughness measurement result shows a sharp decline from the start of polishing. In addition, if the polishing process continues until certain polishing time, the surface roughness declining rate becomes slower and finally saturated. Moreover, the time leading up to the saturation value is different in each injection speed condition. Where higher injection speed shorten the time for the surface roughness to saturate and lower its saturation level. In the fixed-point observation of the surface morphology transition by laser microscope, under injection speed of 12.3 m/s, no significant change was observed. While a polishing characteristics was observed under the injection speed of 31.4 m/s or more, where the polishing progresses while leaving the contour shape of before the polishing process. In addition, from the result of measuring polishing rate of peak, valley and flat plain part of the contour, revealed that the highest polishing rate was obtained in the 30 seconds polishing time zone regardless of polishing media injection speed condition. Also, the polishing rate is the highest at the peak of the contour, then decrease in the order of flat plain part and valley. The polishing rate of valley is about 75% of the polishing rate of the flat plain part.

Regarding the factors of polishing media injection angle, the rate of surface roughness decrease for injection angle of 45 degrees is the highest, and then the rate becomes lower for other injection angle in the order of 15 degrees, 75 degrees and finally 90 degrees. It was revealed that the reduction of surface roughness value is by the large contribution of vector forces during the impact with the work surface. These vector forces is the horizontal component force, the abrasive grain removal force that remove the process surface and the vertical component force, the abrasive grain biting force that bite the work surface. The polishing rate (polishing removal depth per unit of time) was at the maximum under injection angle 45 degrees and reduced in the order of 90 degrees, 75 degrees and 15 degrees. Thus, in the case of surface processing amount it was revealed that the vertical component force contributes greater that the horizontal component force. However, in the case of surface roughness reduction rate, the injection angle 45 degrees shows the maximum reduction rate, which revealed that the balance between the horizontal component force and vertical component force is important in order to achieved both high surface roughness reduction rate and high polishing rate. Also, from the fact that the work surface is not flattened in the condition of injection angle 90 degrees, it revealed that the horizontal component force is essential in smoothing the machined surface.

For the factors of polishing media water content influence to the polishing mechanism on cemented carbide substrate, firstly, regarding the experiment of changing the kinetic energy of the polishing media by changing the mass thru varying the water the polishing media absorbed. The result were compared with the experimental result of varying the kinetic energy by changing the polishing media injection speed obtained in previous section. As a result, in the case of polishing media water content of 10%, although at the lowest kinetic energy when compare to other water content at the maximum injection speed condition, the surface roughness declining rate was the highest where the surface roughness decline sharply from the start of polishing. However, when saturated it saturated at the greater value in comparison with higher water content conditions. Moreover, a lot of scratch marks were observable on the process surface polished with water content of 10% white these scratch mark becomes less presence at higher water content conditions.

In **Chapter 4**, entitled "**Polishing mechanism on cemented carbide substrate by blast polishing process**", from the interesting results obtained from the factors discusses in Chapter 3, the polishing mechanism on cemented carbide substrate by blast polishing process is investigated. At first, we will discuss regarding the factors of increasing the polishing media injection speed could obtained a smooth surface in short time. The polishing media abrasive grain bite amount which control the magnitude of the polishing rate is affected by the work surface hardening. By the surface hardening measurement results, it was confirmed that the hardness of the process surface increase proportionally with the increase of injection speed. Therefore, as the polishing media injection speed increase, it becomes more difficult for the polishing media abrasive grain to bite deeply into the work surface due to surface hardening. While, as the abrasive grain power to remove the process surface increase with increase in injection speed, the surface roughness decrease sharply and obtained a smooth polished surface in a short period of time. Thus, it revealed that the higher injection speed is found to be effective means of reducing the surface roughness in a short time.

Next, regarding the studies of changing the polishing media water content which resulted to different appearance on the surface properties after the polishing process. When the polishing media water content is changed, the mass of the polishing media is also changed. In addition, since the polishing media core material has viscoelastic properties, the material properties such as the polishing media stiffness and cooling polishing effect are also changed which effect the polishing media processing characteristics. From the experimental result of injecting the polishing media with different water content under same kinetic energy conditions, it was revealed that the surface roughness declining rate was the highest under lower water content condition, water content of 10%, and then followed by water content of 30% and finally water content of 50%. However, when saturated the surface roughness saturated, water content of 10% saturated at the highest level while water content of 50% at the lowest. The reason for this phenomena was a result of polishing media stiffness. From the measurement of polishing media modulus of elasticity in each water content conditions, it was revealed that the water content of 10% has the highest modulus of elasticity, about 10 times greater in comparison with water content of 30% and about 15 times greater than water content of 50%. From the observation result of the polishing media deformation behavior when collides with the work surface, no deformation was confirmed for the polishing media water content of 10%. In contrary, under water content of 30% and 50%, a large deformation was confirmed. Furthermore, from the captured footage of the deformation behavior, the impact force applied to the process surface during the collision under each water content conditions is calculated. The calculation results revealed that the impact force for water content of 10% obviously higher, about 3.5 times higher that water content of 30% and 50%. During the collision, due to the high impact force for a water content of 10%, the force to remove the work surface, referred to as grinding length, was higher when compared to a water content of 50%. As a result, the water content at 10% resulted in a high surface roughness decline rate compared to the other water content conditions, however when the surface roughness becomes saturated, it saturates higher than the other conditions. Additionally, the existence of scratch marks on the polished surface using a water content of 10% was due to the abrasive grain bite deeply into the work surface.

Therefore, in conclusion, the water content of the polishing media highly influences the polishing characteristics of this blast polishing method. By changing the amount of water absorbed, the viscoelasticity of the polishing media was changed. Hence, the rigidity of the core material to support the abrasive grain was also changed which resulted in different impact force applied to the work surface during the collision. This eventually affects the polishing behavior of the process and resulted in a different finished surface condition.

In **Chapter 5**, entitled "**Study on optimal surface property of carbide drill for aluminum alloy cutting**", the drill flute surface was treated using the blast polishing process by choosing the most effective polishing parameters that has becomes clear in the previous study. The main purpose of this chapter was to reveal the optimal surface property of the drill flute surface in order to increase it adhesion resistance and to reduce the cutting force during the cutting. The flute of the drill has a long and complex guide flute part, which function to permit removal of chip and the rake face part, where mostly the adhesion takes places. Therefore it is thought that a different surface condition is required for both parts.

At first, entire range of guide flute surface is treated including the rake face to investigate it influence to the cutting performance. From the investigation of changing the polishing media water content to polish the surface, it was revealed that the cutting force for the untreated drill and the drill treated with water content of 10% and 50% shows a tendency to increase in accordance with the drilling depth. However, in the case of drill polished with water content of 30%, the cutting force continue to stabilized without rising until the end of drilling. Moreover, the surface observation results shows a smooth surface without any trace of grinding mark on the surface. Therefore, it is thought this surface states enable the reduction of cutting force by reducing the friction.

Then, the entire range of drill flute surface is treated by varying the blast polishing parameters, the polishing time and polishing angle, to modify the depth and shape of grinding mark convex and concave. The cutting test is conducted to evaluate the cutting performance with more holes drilled. It was revealed that at the initial cutting test, the most polished drill shows the lowest cutting force value both in average value and maximum value, but when more drilling test is conducted, finally the cutting force increase and the amount of adhesion on the drill shows the highest value. While, the untreated drill with the grinding mark textures on the surface shows the lowest cutting force and amount of adhesion. From these results, it is thought that the grinding mark texture somehow has an influence the drilling process by lowering the cutting force. It is considered that the grinding mark function as the lubricant pocket, reservoir for the lubricant oil to retain inside it during the severe sliding contact between the chip and tool surface. Thus, it can be conclude optimal surface condition for the rake face should be with the grinding mark textures.

Further observation of the cutting force by the relation of drilling time and drilling depth when drilling the 100th holes reveals that the cutting force shows sudden rise and finally peaked and stay stagnant after certain drilling depth. However, the untreated drill shows a delay in rising until 10 mm of drilling depth before reaches peaked and start to stagnant at 16 mm of depth. This indicate that the guide flute function as to alloys chip discharge and fluidity of the lubricant oil has deteriorated. It is thought to be due to the existence of grinding mark texture on the guide flute surface that increase the friction between the chip and the surface and also distract the lubricant fluidity. From the experiment of changing the polishing range of the guide flute by leaving 16 mm from the cutting edge untreated, G.F polished drill, revealed that the average and maximum cutting force is further lowered compare to the drill with all flute is untreated. From the observation of the cutting force line with its relation to drilling depth, it was revealed that the G.F polished drill successfully delayed that sudden rise of the cutting force to until 11 mm of drilling depth and also slowing the rising from reaching it peaked until 20 mm of depth. In addition, the cutting force line is reduced effectively from start to the end of drilling even after 300th holes of drilling. These results indicate that the guide flute mirror polished surface reduces the friction on the surface thus increase the fluidity of the lubricant to flow efficiently along the flute in accordance with the depth of drilling. Moreover, as the lubricant able to reach until the rake face, it optimized the function of the grinding mark on the rake face and also allowing the generated chip to be discharge easily together with the lubricant. Therefore, it can be conclude that the optimal surface condition for the guide flute should be mirror polished surface.

In **Chapter 6**, entitled "**Effects of grinding mark texture to the adhesion behavior of aluminum alloy**", to further investigate the function of grinding mark in reducing the cutting force and increase the adhesion resistance, a friction test is conducted by sliding the work piece by certain load on the carbide substrate surface with and without the grinding mark textures. This experiment was also to provide strong evidence for the consideration of the grinding mark in the previous chapter.

From the friction test conducted under dry condition, it was revealed that the lowest amount of adhesion was on the surface with the existence of the grinding mark textures in the condition if the friction test is vertical with the direction of the grinding mark. For the case of the smoothest surface condition, greater area of adhesion was observable and the adhesion amount is the highest. However, if the test is conducted parallel with the direction of the grinding mark, no significant differences can be observed in each carbide substrate surface conditions. In addition, from the observation of the adhesion behavior on the surface, in the case of surface with grinding mark textures, the adhesion was observed only top of the convex portion of the grinding mark. While, as the grinding mark is removes the adhesion spread to the entire surface.

In addition, the results of friction coefficient reveals that during the initial friction test, the smoothest surface shows lower friction coefficient value, while the surface with the grinding mark shows the highest value. But, when the friction test continues, although the friction coefficient in all surface condition increased, the increment for the surface with grinding mark is slower compare to the smoothest surface. Finally, the friction coefficient for the surface with grinding mark end up to be the lowest compare to other surface conditions. From these result it can be concluded that the grinding mark textures reduces the contact area of the surface with the work piece thus reduces the friction. As only the convex portion of the grinding mark touches the work piece, the adhesion only occurs on portion. While for the smoothest surface conditions, although initially the friction coefficient is lower, however due to large area of contact with the work piece, the adhesion is easily generated and created a thin adhesion film on the surface. When the number of test increased, the adhesion layer grow thicker and worsen the surface condition. Therefore the friction coefficient increase faster and finally resulted to the highest friction coefficient value at the end of test.

For the friction test under wet condition, initial friction test revealed that almost no significant different in the friction coefficient value for both polished surface and the surface with grinding mark. However, at the final friction test, it was observable that the friction coefficient for the polished surface increase higher than the initial test results. On the other hand, the friction coefficient for the surface with grinding mark shows the friction coefficient decrease lower while the value under vertical test direction shows the lowest.

In conclusion, these result revealed that the grinding mark are able to function at its full maximizes under wet condition with lubricant oil. This is because the lubricant oil accumulates the concave portion of the grinding mark and reduces the area of contact between the surface and the work piece thus improves the friction coefficient and prevent the adhesion to grow. Furthermore, the reason of the reduces in the friction coefficient in accordance with the increase of friction test indicates that the lubricant oil gradually becomes acquainted with the surface conditions by accumulation in the concave portion of the grinding mark which resulted to the improved the friction resistance. From the surface observation result of the test in parallel direction with grinding mark, the concave portion of the grinding mark textures is blacker compare to the observation before the friction test. The black area is the adhesion area by the work piece. It is thought that under parallel test direction, the grinding mark cannot function completely. Although it able to reduces the contact area between the surface and the work piece, however under parallel test condition, the grinding mark concave cannot function as the lubricant pocket properly where the lubricant is not seal completely inside the concave to prevent the adhesion from entering it. The lubricant is forcedly pushed out from the concave by the work piece during the contact deposited onside the concave. As the friction test continues, the concave is slowly filled out by the deposition of the work piece. In the end resulted to the higher friction coefficient value when compare to the vertical test direction. However, as long as the concave portion is not filled by deposition of work piece material by adhesion, the friction coefficient is considered less likely to worsen.

7.1.1 Conclusion remarks

Chapter 3, "Effect of several factors in blast polishing process on surface condition of cemented carbide".

[Influence of polishing media injection speed on the process surface]

1. At higher injection speed, particularly 59.5 m/s, the polishing progress was observed clearly where the surface gradually flattens and also shows the tendency to saturated faster.
2. From the observation of the surface morphology it was revealed that highest polishing rate was achieved within 30 seconds of the polishing process.
3. The maximum injection speed 59.5 m/s is recommend in this polishing process in order to achieved high polishing efficiency.

[Influence of polishing media injection angle on the process surface]

1. It was revealed that an injection angle of 45 degrees shows the highest surface roughness decline rate and no surface flattening for an injection angle of 90 degrees.
2. Injection angle of 45 degrees was suggested as the most efficient angle to achieve a high surface roughness decline rate and a high amount of surface removal due to the optimized amount of force in vertical and horizontal component force.

[Influence of polishing media water content on the process surface]

1. It was revealed that the surface roughness declining rate for the water content of 10% soon after the start of polishing is the highest, and then follows by water content of 30% and finally 50%. However, finally at the saturation level, water content of 10% is in the highest level and water content of 50% is in the lowest level.
2. Water content of 10% has the highest polishing ability, but, the finished surface has a lot of scratch mark on the surface.

Chapter 4, "Polishing mechanism on cemented carbide substrate by blast polishing process".

[<u>Effects of the polishing media water content on the polishing mechanism</u>]

1. Water content of 10% has the highest polishing ability, where it can polish the work surface into flat plain surface in a short time. However, the finished surface has a lot of scratch mark on the surface, created by the abrasive grain during the polishing process due to the hard and less viscoelastic state of the polishing media.
2. The water content of the polishing media highly influences the polishing characteristics of this blast polishing method. By changing the amount of water absorbed, the viscoelasticity of the polishing media was changed. Hence, the rigidity of the core material to support the abrasive grain was also changed which resulted in different impact force applied to the work surface during the collision. This eventually affects the polishing behavior of the process and resulted in a different finished surface condition.
3. It is recommendable to use water content of 30% because of it high polishing efficiency that able to reduces the surface roughness in a short time and the process surface undergo this water content shows smooth clean surface with less presence of the scratch mark

Chapter 5, "Study on optimal surface property of carbide drill for aluminum alloy cutting".

[<u>Optimal surface property for the drill rake face</u>]

1. The untreated drill shows better adhesion resistance and able to reduce the thrust force. This is due to the influence of grinding mark texture on the rake face that provides the lubricant pocket which is the escape holes for the lubricant to retained inside it and reducing the contact are between the interface of tool and chip thus preventing the formation of adhesion.
2. It is concluded that the grinding mark texture is the optimal surface condition for the rake face because it can moderately reduce the cutting force and improved the adhesion resistance

[Optimal surface property for the drill guide flute]

1. The G.F polished drill can further lower the cutting force in both average and maximum value. In addition, the G.F polished drill effectively delayed the rise of the cutting force at the first and second stage of drilling depth and are able to function even after further cutting test was conducted.
2. It was concluded that the optimal surface condition for the guide flute should be without any texture, which is mirror surface condition because it can increase the lubricant oil fluidity which results to further reduce the cutting force and delaying the rise of it.

Chapter 6, "Effects of grinding mark texture to the adhesion behavior of aluminum alloy".

[Effect of grinding mark textures to the adhesion behavior]

1. The grinding mark is fully maximize vertically with the test direction and the grinding mark is full capability under wet conditions.
2. Under wet conditions, particularly under vertical test direction, the lubricant oil accumulates the concave portion of the grinding mark and reduces the area of contact between the surface and the work piece thus improves the friction coefficient and prevent the adhesion to grow.

7.2. Review

The significant of the results obtained in this research and its contribution to the academic sectors and to the industry is summarized and discuss as the following.

7.2.1 Contribution of this study in the academic sectors

There are several research regarding the surface modification on the cutting tool that had been conducted recently. A lot of method had been researched and reported including surface modification by implanting a textures on the surface as well as by polishing the surface. However most of the researches focused on the cutting tool for machining process in turning and milling operation. Very few research is about the cutting tool in drilling process. This is due to the drill geometry itself which has a complex curves surface. Furthermore it is challenging task to evaluate the drill during machining operation due to the cutting process is inside the work piece. The observation of the drilling condition inside, chip formation condition and its flowing condition, as well as the measurement of the temperature generated during the cutting are the main obstacles. In addition, the expensive machining equipment and devices for the evaluation and measurement purpose becomes the major financial problem.

In this study, the cutting force behavior with the relation of drilling time and drilling depth during the cutting process is mainly evaluated to study the cutting performance of the drill. Recently, the blast polishing process had attract attention by the cutting tool manufacturer as its excellent ability to polish complex surface shape and geometry. Therefore for the surface modification on the cutting tool, the blast polishing process is applied to control the condition of the grinding mark textures on the surface as well as to smoothest the surface. From this study, it was clear that a different surface conditions is required in each part of the cutting tool flute surface in order to maximize the potential of the cutting tool. The cutting tool performance is proved to increase by leaving grinding mark textures on the rake face and smoothest the guide flute surface. This is because each flute surface parts function differently by the different work environment during the cutting process. The part near the cutting edge of the flute surface, the rake face work environment is more severe because this surface come to direct contact with the work piece. The chip is generated in this area thus the adhesion formation likely to occur. Therefore, the texture on the rake surface helps to reduce the real contact area between the surface and the work piece by providing a reservoir for the lubricant to retain inside it during the sliding to reduce the friction at the interface. However, it was found that the grinding mark direction is not vertical with the chip flow direction. Therefore it is recommendable to reconstruct the direction of the texture on the rake face to make it exactly vertical with the flow direction of the chip.

The major part of the flute surface is the guide flute. The main function of the guide flute is to allow the excess of lubricant to flow inside the hole and reached until the rake face. Another function is to provide an exit path for the chip generated inside the hole to evacuate. Therefore the work environment for the guide flute is not as critical as the rake face. The guide flute surface is not in direct contact with the chip therefore the adhesion is not likely to occur on the surface. Therefore to allow high lubricant fluidity as well as to increase the flow of discharged chip, the surface condition of the guide flute must be smooth polished surface. By smoothing the surface of the guide flute, the friction on the surface is reduces. As revealed in this study, lower cutting force is obtained and also able to delaying the rise of the cutting force during the drilling.

7.2.2 Contribution of this study to the industry

From this study, the influences of each blast polishing parameters to the surface condition and the polishing mechanism were successfully revealed. Therefore it is hope that this study can contributes to the industry by assisting them to achieve their desired surface conditions by the choosing the optimized polishing parameters. Thus this will increase the production efficiency as well as able to reduce the cost. Furthermore, as it has been revealed in this study that a different surface condition required on the drill flute surface to increase the cutting performance. However, further study regarding the optimal condition of the convex and concave shape as well as the optimal pitch and height should be conducted. This is because, it is thought that in each cutting conditions a different optimal texture is required. For example, under wet cutting condition, a texture with deep and narrower concave is preferable whereas under dry cutting condition probably different texture condition is required. In addition, different work material required its own optimized textures condition. This is because different work material has different workability due to different melting point and hardness. Hence, further research regarding this subject is ought to be conducted and when it has becomes clear, the production of a custom cutting tool for each cutting condition can be developed. Thus more specific value can be added as the selling point to make it more competitive in the market.

8. Future perspectives

In this thesis, a research regarding the optimal surface property for the drill flute surface by surface modification using blast polishing process has been conducted. It was revealed that the optimal surface conduction for the drill rake face is with grinding mark textures and the optimal surface for the drill guide flute surface is the smooth polished surface.

Regarding the grinding mark textures on the rake surface, from the result of friction test, it was revealed that grinding mark textures fully function at its maximum ability when the test direction is vertical with direction of the grinding mark. However, from the observation to confirm the flow angle of the chip with the grinding mark direction on the drill rake face, it was found that the chip flow direction is at approximately 45 deg. with the direction of the grinding mark. Which is different from the optimal direction condition obtained from the friction test. Hence, it is thought that if the direction of the grinding mark is vertically with the chip flow direction, the adhesion resistance on the rake face can further be improved and lower cutting force value can be obtained. For this reason a development of the grinding mark textures on the drill rake face that is vertically with respect to the chip flow direction will be conducted in the future. As the drill rake face is a complex curved surface, the development of the grinding mark texture is a challenging task. For now, the most applicable method is by the diamond brush grinder and by laser texturing using femtosecond or picosecond laser. Though, texturing by laser is more preferable as the texture can be implant on the surface uniformly. Also, further study regarding the optimal condition of the convex and concave shape as well as the optimal pitch and height can be conducted by laser texturing method as the pattern can be design limitlessly. This is because, it is thought that in each cutting conditions a different optimal texture is required. For example, under wet cutting condition, a texture with deep and narrower concave is preferable whereas under dry cutting condition probably different texture condition is required. Hence, further research regarding this subject is ought to be conducted and when it has becomes clear, the production of a custom cutting tool for each cutting condition can be developed. Thus more specific value can be added as the selling point to make it more competitive in the market.

Regarding the drill guide flute surface, from this study, is was clear that the guide flute with smooth polished surface without any grinding mark textures able to reduces the cutting force and delaying the rise of cutting force deeper into the drilled holes. Also, this effect is still maintain even after further holes drilled. It is concluded that by polishing the guide flute surface reduces the friction on the surface that improves the fluidity of the lubricant oil and allowing the chip to be discharged easily. However, further study is required for the evidence of this consideration. Therefore, in the future a study of the effect of mirror polished guide flute by an observation of the lubricant fluidity and the condition of the chip evacuation along the guide flute will be conducted to provide a strong evidence of the hypothesis.

Furthermore, a study regarding the influence of changing the polishing range of the guide flute should be conducted. In this study, by referring the rise of cutting force with the relation of drilling depth, the drill rake face and part of the guide flute which is 16 mm from the cutting edge is left untreated. But, it is thought that maybe by reducing the untreated range below 16 mm, or maybe by leaving only the rake face untreated, probably can further delayed the cutting force rise and reduces it even lower. Also, the influence of treatment time by the blast polishing process should further be investigated. Polishing time only until 3 minutes/flute is investigated in this study. From the study of the relation between polishing time and surface roughness of the blast polishing process, it takes at least 90 seconds of polishing process before the surface roughness saturated in static polishing condition. Therefore, it is thought that longer polishing time is required to polish the drill guide flute before the surface roughness saturated. Although 3 minutes polishing able to removes the grinding mark textures on the surface, longer polishing treatment should be able to further reduces the surface roughness value to the saturation level. Smoother surface able to reduces the friction ever lower and is thought to effect the cutting performance. In the future, more study regarding this factor will be conducted to confirm this hypothesis.

9. References

[1] Japan Small Business Corporation, “FMC Introduction - design and implementation and operation of flexible production,” *Nikkan Kogyo Shimbun, Ltd.*, Nikkan Kogyo Shimbun, Ltd., p. 13, 1986.

[2] T. Obikawa, “On Mechanisms of High Speed and Ultra High Speed Machining,” *Prod. Res.*, vol. 56, no. 6, pp. 471–476, 2007.

[3] Y. Nakamura, “New technology to see the next generation of CNC tool grinder (new technology of the latest grinding machine seen in another Feature 1 field),” *Mach. tools*, vol. 48, no. 6, pp. 25–29, 2004.

[4] T. Yoshida, “Tools of machine high-precision CNC tool grinder of the foundation to use the future foundation: the Makino Seiki Co., Ltd., Ed., (1st) high-precision CNC tool grinder,” *Mach. Technol.*, vol. 61, no. 8, pp. 68–71, 2013.

[5] T. Yoshida, “Basis of high-precision CNC tool grinder of the foundation to use machine tools now: Makino Seiki Co., Ltd., Ed., (3rd) peripheral equipment to support the tool grinding and software,” *Mach. Technol.*, vol. 61, no. 10, pp. 69–73, 2013.

[6] T. Enomoto and T. Sugihara, “Improving anti-adhesive properties of cutting tool surfaces by nano-/micro-textures,” *CIRP Ann. - Manuf. Technol.*, vol. 59, no. 1, pp. 597–600, 2010.

[7] T. Enomoto, T. Sugihara, S. Yukinaga, K. Hirose, and U. Satake, “Highly wear-resistant cutting tools with textured surfaces in steel cutting,” *CIRP Ann. - Manuf. Technol.*, vol. 61, no. 1, pp. 571–574, 2012.

[8] N. Kawasegi, H. Sugimori, H. Morimoto, N. Morita, and I. Hori, “Development of cutting tools with microscale and nanoscale textures to improve frictional behavior,” *Precis. Eng. J.*, vol. 33, pp. 248–254, 2009.

[9] T. Sugihara and T. Enomoto, “Improving anti-adhesion in aluminum alloy cutting by micro stripe texture,” *Precis. Eng.*, vol. 36, no. 2, pp. 229–237, 2012.

[10] T. Sugihara and T. Enomoto, “Development of a cutting tool with a nano/micro-textured surface-Improvement of anti-adhesive effect by considering the texture patterns,” *Precis. Eng.*, vol. 33, no. 4, pp. 425–429, 2009.

[11] J. Kummel, J. Gibmeier, E. Muller, R. Schneider, V. Schulze, and A. Wanner, “Detailed analysis of microstructure of intentionally formed built-up edges for improving wear behaviour in dry metal cutting process of steel,” *Wear*, vol. 311, no. 1–2, pp. 21–30, 2014.

[12] J. Kummel, D. Braun, J. Gibmeier, J. Schneider, C. Greiner, V. Schulze, and A. Wanner, “Study on micro texturing of uncoated cemented carbide cutting tools for wear improvement and built-up edge stabilisation,” *J. Mater. Process. Technol.*, vol. 215, pp. 62–70, 2015.

[13] M. Furuno, K. Kitajima, and Y. Tsukuda, “Effects of tool ground surface roughness on adhesion characteristics by PVD coating,” *J. Japan Soc. Abras. Technol.*, vol. 54, no. 11, pp. 666–671, 2010.

[14] M. Furuno, K. Kitajima, Y. Tsukuda, and T. Akamatsu, “Effects of ground surface roughness of tool on adhesion characteristics by PVD coating, 2nd report: Effects of cutting characteristics by coating and surface roughness,” *J. Japan Soc. Abras. Technol.*, vol. 55, no. 1, pp. 48–53, 2011.

[15] L. A. Dobrzanski, M. Polok, P. Panjan, S. Bugliosi, and M. Adamiak, “Improvement of wear resistance of hot work steels by PVD coatings deposition,” *J. Mater. Process. Technol.*, vol. 155–156, no. 1–3, pp. 1995–2001, 2004.

[16] H. Yoshida, *Basis of “polishing process.”* 2012.

[17] Y. Inoue, M. Liu, J. Takagi, T. Tanaka, and T. Tukasaki, “Study on Dry Drilling for Aluminum Alloy (4th Report),” *2004 Precis. Eng. Soc. Annu. Spring Conf. Proc. Sch. Lect.*, pp. 625–626, 2004.

[18] K. Yamashita, K. Kitajima, K. Hamada, and G. Kuratani, “Mirror polishing and deburring technology by AERO LAP,” *J. Japan Soc. Abras. Technol.*, vol. 52, no. 2, pp. 66–69, 2008.

[19] K. Yamashita, “Deburring and Edge Finishing by Mirror-shot Polishing ‘Aero Lap,’” *Mach. Technol.*, vol. 58, no. 13, pp. 34–36, 2010.

[20] K. Kitajima and K. Yamashita, “Blast polishing by utilizing of multi-corn media,” *J. Japan Soc. Abras. Technol.*, vol. 50, no. 9, pp. 505–508, 2006.

[21] H. Sakaeju, “Mirror-shot polishing technique,” *Mach. Technol.*, vol. 54, no. 10, pp. 29–31, 2006.

[22] Editorial department, “Towards the optimization of the mold surface finish Apuro: Case 4, simplification of the mirror finish by Aero wrap method,” in *Type technology*, 2016, pp. 048–051.

[23] K. Yamashita, “Polishing method using a water-containing polishing media ‘Aerolap method,’” *Mach. Technol.*, vol. 54, no. 10, pp. 34–36, 2006.

[24] K. Kitajima, T. Fuji, and K. Kano, “Study on Blast polishing utilizing animal protein media,” *2005 Precis. Eng. Soc. Annu. Fall Meet. Sch. Lect. Proc.*, pp. 1115–1116, 2005.

[25] K. Kitajima, E. Yamane, and K. Yamashita, “Study on Blast Polishing Utilizing Animal Protein Media (2nd Report),” *2007Precision Eng. Soc. Annu. Spring Conf. Proc. Sch. Lect.*, pp. 1129–1130, 2007.

[26] K. Ramesh, S. Ozbayraktar, and H. Saridikmen, “Aero-lap polishing of poly crystalline diamond inserts using Multicon media,” *J. Manuf. Process.*, vol. 14, no. 2, pp. 167–173, 2012.

[27] H. Sakaeju, “Next-generation mirror-shot technology,” *J. Japan Soc. Abras. Technol.*, vol. 48, no. 11, pp. 605–608, 2004.

[28] K. Ohashi, E. Sogabe, N. Lu, M. Fujihara, T. Onishi, and S. Tsukamoto, “Fundamental study of cylindrical blasting,” *J. Japan Soc. Abras. Technol.*, vol. 56, no. 9, pp. 626–631, 2012.

[29] F. Yamamoto, T. Uemura, K. Ogawa, and O. Kazuo, “Improvement of Measurement Accuracy of Particle Tracking Velocimetry Using Binary Correlration Method,” *Japan Soc. Mech. Eng.*, vol. 57, no. 543, pp. 3926–3931, 1991.

[30] F. Yamamoto, T. Uemura, M. Koukawa, M. Iguchi, and S. Yoshihide, “Binary Correlation Method for 2D-PTD and its Application to Two Cylinder Interaction Flow,” *Univ. Fukui Fac. Eng. Res. Rep.*, vol. 40, no. 1, pp. 31–38, 1992.

[31] M. Nizar, K. Takai, M. Uemura, and M. Fukumoto, “Polishing mechanism of cemented carbide using blast polishing process, 1th report : Effects of injection speed and polishing time on surface roughness,” *J. Japan Soc. Abras. Technol.*, vol. 57, no. 4, pp. 253–258, 2013.

[32] K. Kitajima, K. Minaki, K. Minaki, and M. Izawa, “Study on Improvement of Surface Texture of Stainless Steel by Utilizing Dry Blasting, 1st Report: Effect of blasting conditions on surface

texture," *J. Japan Soc. Abras. Technol.*, vol. 49, no. 1, pp. 30–35, 2005.

[33] K. Toya and K. Iida, "On the Characteristics of Grit Blasted Surface and Affected Layer," *Precis. Eng. J.*, vol. 53, no. 2, pp. 269–274, 1987.

[34] K. Toya and K. Iida, "Stock Removal Produced by Grit Blasting," *Precis. Eng. J.*, vol. 54, no. 06, pp. 1132–1137, 1988.

[35] K. Toya and K. Iida, "Stock Removal Mechanism of Grit Blasting," *Precis. Eng. J.*, vol. 58, no. 12, pp. 2025–2030, 1992.

[36] K. Toya and K. Iida, "Processing Conditions and the Fatigue Strength of the Shot Peening," *Precis. Eng. J.*, vol. 51, no. 8, pp. 1569–1574, 1975.

[37] E. Takeuchi, "Wear and Countermeasures of Mechanical Parts, (Parts 1): Wear Mechanism," *Met. Surf. Technol.*, vol. 22, no. 11, pp. 602–606, 1971.

[38] S. Atlati, B. Haddag, M. Nouari, and A. Moufki, "Effect of the local friction and contact nature on the Built-Up Edge formation process in machining ductile metals," *Tribol. Int.*, vol. 90, pp. 217–227, 2015.

[39] M. Nizar, K. Takai, M. Uemura, and M. Fukumoto, "Study on polishing mechanism of cemented carbide using blast polishing process, 2nd report : Effect of kinetic energy and injection angle on surface condition of cemented carbide," *J. Japan Soc. Abras. Technol.*, vol. 58, no. 6, pp. 386–391, 2014.

[40] A. W. Batchelor and G. W. Stachowiak, "Tribology in materials processing," *J. Mater. Process. Technol.*, vol. 48, no. 1–4, pp. 503–515, 1995.

[41] H. Takeyama and T. Ono, "Basie Investigation of Built-Up-Edge," *apan Soc. Mech. Eng.*, vol. 10, no. 39, pp. 558–565, 1967.

[42] A. Gomez-Parra, M. Alvarez-Alcon, J. Salguero, M. Batista, and M. Marcos, "Analysis of the evolution of the Built-Up Edge and Built-Up Layer formation mechanisms in the dry turning of aeronautical aluminium alloys," *Wear*, vol. 302, no. 1–2, pp. 1209–1218, 2013.

[43] M. S. Carrilero, R. Bienvenido, J. M. Sanchez, M. Alvarez, A. Gonzalez, and M. Marcos, "A SEM and EDS insight into the BUL and BUE differences in the turning processes of AA2024 Al-Cu alloy," *Int. J. Mach. Tools Manuf.*, vol. 42, no. 2, pp. 215–220, 2002.

[44] S. Bhowmick and A. T. Alpas, "Minimum quantity lubrication drilling of aluminium-silicon alloys in water using diamond-like carbon coated drills," *Int. J. Mach. Tools Manuf.*, vol. 48, no. 12–13, pp. 1429–1443, 2008.

10. Publication lists

List of Paper/Journals with Referee's Review

1. Mohd Nizar, Naoya Arimatsu, Hiroshi Kawamitsu, Kazuteru Takai, and Masahiro Fukumoto, "Study on optimal surface property of WC-Co cutting tool for aluminium alloy cutting," Materials Science and Engineering, Vol. 114(1), pp. 012024(1-10), 2016
2. Masahiro Fukumoto, Kazuteru Takai, Mohd Nizar, Naoya Arimatsu, and Masao Uemura, "Study on polishing mechanism of cemented carbide by means of blast polishing, 3rd report: Influence of water content in polishing media on polishing mechanism," Journal of the Japan Society for Abrasive Technology, Vol. 60 No.5, pp. 261-266, 2016

List of Papers at International Conference with Referee's Review

1. Mohd Nizar M. R, Naoya Arimatsu, Kazuteru Takai and Masahiro Fukumoto, " Polishing mechanism of blast polishing process on cemented carbide," International Tribology Conference Tokyo 2015, Japanese Society of Tribologists 2015, pp. 17P-31(1052-1053), 2015.09.17, Tokyo, Japan

International Conference Participations

1. Mohd Nizar M. R, Naoya Arimatsu, Kazuteru Takai and Masahiro Fukumoto, “Polishing mechanism of blast polishing process on cemented carbide,” International Tribology Conference Tokyo, Tokyo, Japan, September, 2015
2. Mohd Nizar, Naoya Arimatsu, Hiroshi Kawamitsu, Kazuteru Takai, and Masahiro Fukumoto, “Study on optimal surface property of WC-Co cutting tool for aluminium alloy cutting,” Joint conference of International Manufacturing Engineering Conference & Asia-Pacific Conference of Manufacturing System, (IMEC 2015 & APCOMS 2015), Kuala Lumpur, Malaysia, November, 2015

Local Conference Participations

1. Mohd Nizar, Kazuteru Takai, Masao Uemura and Masahiro Fukumoto, “Effect of water content of the polishing media in blast polishing method on the surface finish of the cemented carbide” Japan Society of Mechanical Engineers Tokai Branch 63rd General Assembly Lecture Proceedings, Japan Society of Mechanical Engineers, Nagoya, March, 2014

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