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An Examination on Improving WEDM and Vacuum Brazing Process Failure of PCD Tool

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Abstract

Background/Objectives: It aims to improve the tool lifespan by improving defects in WEDM(Wire Electric Discharge Machining) and vacuum brazing process, which are PCD(Polycrystalline Diamond) tool making process.

Methods/Statistical analysis: When machining a PCD disk plate by WEDM processing the elution of the binder on the PCD surface by the electrolyte is measurement by a tool microscope and compared. In addition, when the PCD tip and base material are bonded by the vacuum brazing process, the deflective strength of biding section is measurement.

Findings: PCD disk plate was processed by WEDM machining, it was compared that the binder of the PCD surface was eluted according to the level of exposure to the electrolyte. When the PCD disk plate was precipitation of the electrolyte for about 10 minutes, about 70% of the binder eluted. However, when the SM45C plate was attached to the PCD surface, of binder an elution was drastically lowered. The deflective strength of the joints with temperature was measured in vacuum brazing, which is the binding process between PCD tip and base material. When vacuum brazing was applied by a temperature pattern with a maximum temperature rise a 690℃ the deflective strength of the joint between the PCD and the material was measured to be 430[N/mm2].

Improvements/Applications:The level of elution of the binder was determined according to the time of exposure of the PCD surface to the electrolyte. In addition, it was confirmed that the bonding strength was improved by the melting temperature condition of the filler metal for vacuum brazing.It may be applied to manufacturing processes of various rotating tools like end mill, drill cutting tool, etc.

Keywords: deflective strength, binder elution, PCD tool, vacuum brazing, WEDM, electrolyte

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I. Introduction

With the development of industry and the development of industries of transportation, the field of machining has grown. In order to, the use of tools for machining a variety of workpieces is increasing rapidly. Particularly, part of machines that are responsible for transporting automobiles, airplanes and ships require high precision and durability. Reliability of tool lifespan and quality is very important for machining and mass- producing parts of such machines[1]. As a tool material, diamond has high hardness, high thermal conductivity, low friction and abrasion resistance. Diamond has excellent surface roughness and machining dimensional accuracy in machining workpieces using malleable nonferrous alloys and non-metallic materials with high abrasiveness, and is used in ultra-precision parts machining[2]. Generally, Diamond are classified into natural diamond and synthetic diamond, and natural diamond are classified as jewelry and industrial depending on the amount of internal impurities. Synthetic diamonds are classified into monocrystalline diamond and polycrystalline diamond. Industrial grade natural diamond are expensive and have difficulty in making tools because of their abrasive properties depending on crystal formation orientation. Therefore, recently, the ratio of using synthetic single crystal diamond or PCD(Polycrystalline diamond) produced for industrial use is increasing[3]. PCD, which is a polycrystalline diamond, is obtained by mixing a plurality of diamond particles with a binder such as cobalt, fusing them in a state of high temperature and high pressure, and then pressing and sintering the cemented carbide as a base material[4]. To make a PCD tool, the PCD disk plate should be shaped to a size suitable for the tool. PCD disk plate shape processing uses WEDM(Wire Electric Discharge Machining), which minimizes material loss and facilitates the processing of various shapes. WEDM is a method of machining PCD disk plate precipitated in an electrolyte using wires that generate discontinuous discharges. At this time, cobalt, which is a binder for holding the PCD particles, is eluted by the electrolyte and irregular oxidation occurs on the cutting surface[5]. Such elution of cobalt and irregular oxidation accelerates the deviation of PCD particles and degrades tool life[6]. Therefore, it is necessary to minimize changes in the machining conditions of the WEDM and the exposure of the electrolyte to improve the elution of the binder and the irregular oxidation which lowers the lifespan of the PCD tool[7].

Vacuum brazing is used to bind the shaped PCD tip to the shank. For vacuum brazing, filler metal is applied between the PCD tip and the base material shank. A synthetic metal filler such as silver alloys and copper alloys is used for the filler metal[8]. Synthetic filler metal is not a solid solution in which each metal material is mixed. Therefore, the composition ratio of each metal material is changed unless it is completely mixed. Moreover, some metallic material floats and forms a layer after a lapse of time after the stirring operation is completed[9]. Therefore, when the agitating operation of the filler metal is not suitable or when a lot of time passes after stirring operation, particles of filler metal and many air voids are formed between the PCD tip and the shank. These filler metal particles and many air voids are between the PCD tip and the shank and this may weaken binding force of a binding section. If the vacuum brazing temperature is excessively increased to melt the filler metal more, it will damage the PCD tip[10,11].

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Therefore, this study is aimed to minimize the elution of the binder caused by exposure to the electrolyte in the WEDM process for the shape machining of PCD tip. In order to improve the binding force between PCD tip and shank, the optimum melting temperature condition for filler metal is selected during vacuum brazing.It is intended to improve the reliability of the tool by improving the lifespan of the PCD tool.The figure 1 shows PCD tools.

Figure 1. PCD Tools (Champ Dia. Co)

II. Materials and Methods

To design a PCD tool, WEDM should be used to machine a PCD plate into a required dimension and this machined PCD should be bound to a shank through vacuum brazing with filler metal. PCD is exposed to electrolyte in a WEDM process and a PCD surface exposed has elution of cobalt a binder to hold PCD particles and in vacuum brazing process, some binder is eluded under a high temperature. This eluded binder weakens a binding force of PCD and a place with binder elution gets chips of materials grinded from cutting and processing to have build-up edge, causing reduction of lifespan of a tool.To minimize binder elution from machining, grinding and vacuum brazing of PCD a cause of binder elution should be determined and analyzed. To find this cause of elution and to improve a process a PCD surface was observed with a toolmaker's microscope whenever each process was completed from the initial process.

Moreover, to resolve defect of binding section due to poor melting of filler metal and PCD damage due to incongruence of temperature condition in vacuum brazing for binding between PCD and shank, a temperature condition was set to observe a binding section with a toolmaker's microscope through vacuum brazing and to confirm a binding force of binding section a deflective test was performed.At first, to check binder elution due to exposure of electrolyte within a WEDM process each process was completed with three-stage conditions of plate status, exposure status and non-exposure status and the PCD surface was observed with a toolmaker's microscope. Moreover, the binder elution level from grinding of sintered carbide parent material was checked to adjust the height of PCD.

To check the binder elution level under the temperature in the binding process the case with brazing under the conventional high melting point flux and the case with brazing under the low melting point flux were compared. Furthermore, through confirmation of the melting temperature condition of filler metal and the damage of upper surface of PCD from vacuum brazing, the brazing temperature condition was set and vacuum brazing was performed to check the binding force of the binding section and to check the surface of binding section and the deflective test to check the binding force was performed.

The Figure 2 shows the image of PCD plate and the Figure 3 shows the measure to prevent exposure of PCD to electrolyte. To prevent exposure to electrolyte, 0.1[mm] double-sided tape was attached on the PCD plate and to make it to be conductive the 1[mm] thick SM45C was attached.

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Figure 2. PCD disk plate(Blank)

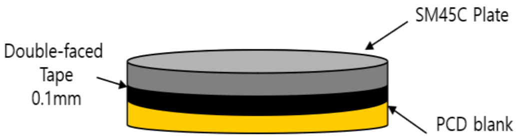

Figure 3. Image of PCD with sample to prevent exposure to electrolyte

The Figure 4 shows the toolmaker's microscope to observe the PCD surface and the Figure 5 shows the vacuum brazing equipment to perform binding of PCD and shank.

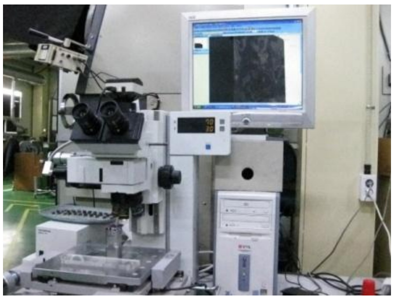

Figure 4. Toolmaker's microscope(SMT-6)

Figure 5. Vacuum brazing machine

III. Results and Discussion

In this study, the sample was designed to minimize the binder elution within the WEDM process for machining of the PCD plate. The Figure 6 and the Figure 7 indicate the initial surface of the PCD plate. As shown in the figures, the white dots on the surface are cobalt, or the binder.

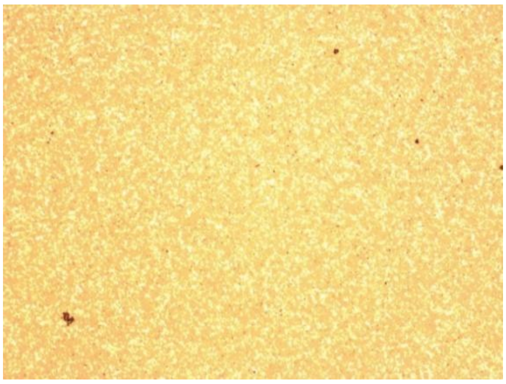

Figure 6. PCD plate surface (x200)

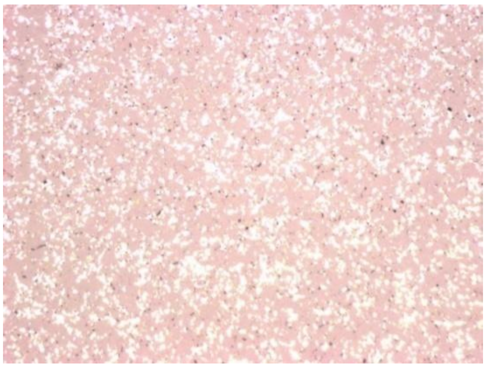

Figure 7. PCD plate surface (x500)

The Figure 8 and the Figure 9 show the PCD surface after the conventional WEDM process. As shown in the figures, the block dots are trace of disappearance of the binder.

Figure 8. PCD surface after WEDM process (x200)

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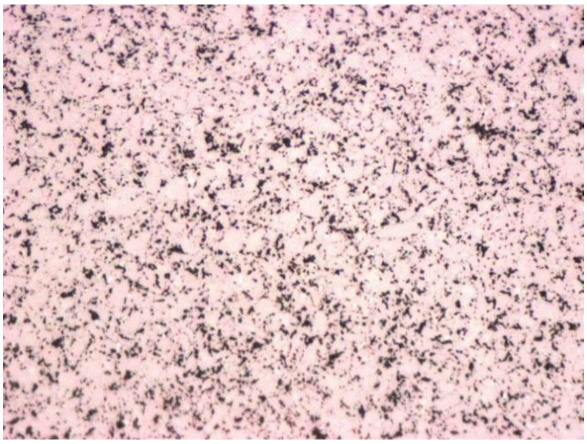

Figure 9. PCD surface after WEDM process (x500)

The Figure 10 shows the PCD surface after WEDM processing under changed electrolyte condition and electric condition for PCD machining. As shown in the figure, changes in electric conditions and electrolyte conditions could not minimize the binder elution.

Figure 10. WEDM process PCD surface after changing electric condition and electrolyte condition

The Figure 11 and the Figure 12 show the PCD surface with the sample to prevent exposure to electrolyte in the WEDM process for PCD machining. As shown in the figure, the binder elution could be minimized by preventing exposure to grinding solution.

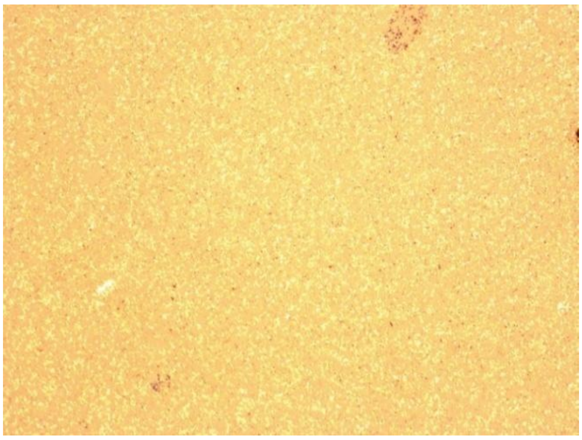

Figure 11. WEDM process PCD surface with agent preventing electrolyte exposure (x200)

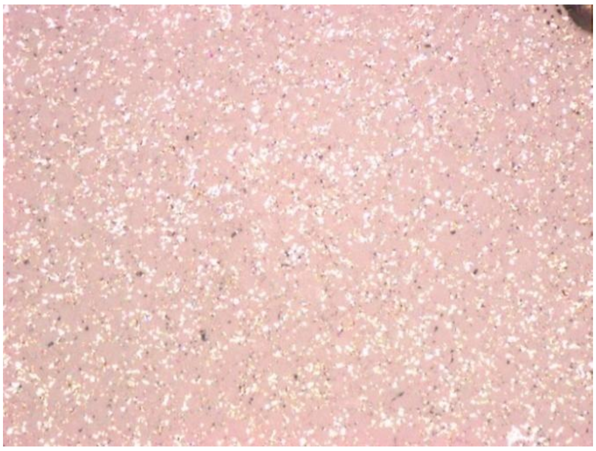

Figure 12. WEDM process PCD surface with agent preventing electrolyte exposure (x500)

After WEDM processing to adjust a thickness of PCD tip there is a grinding process of sintered carbide a parent material of PCD to adjust a thickness of PCD tip. In this process the elution of cobalt or a binder was shown from chemical reaction between grinding solution and binder. Hence, to minimize the binder solution by grinding solution, grinding solution should be replaced and a measure to minimize grinding time to shorten exposure to grinding solution are required. In this study, the exclusive jig and working platform were installed to minimize the exposure time to conventional grinding solution.

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The Figure 13 indicates the PCD surface prior to exposure to grinding solution and the Figure 14 shows the PCD surface after 10 minutes of exposure to grinding solution. As shown in the figures, about 70% of binder was eluded.

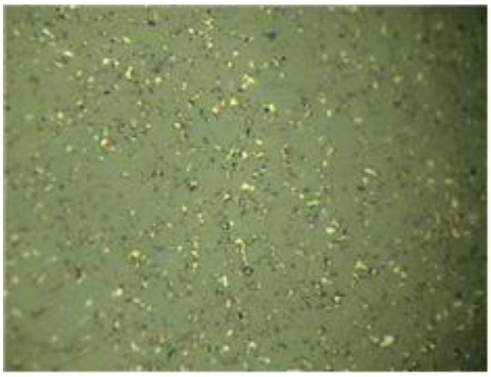

Figure 13. PCD surface prior to exposure to grinding solution

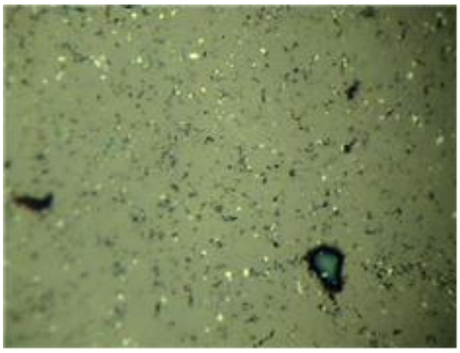

Figure 14. PCD surface after 10 minutes of exposure to grinding solution

For binding between PCD and shank, high-frequency brazing was implemented and after this binding process, still many binders eluded. The cause of binder elution was predicted to be the heat from binding and thus the case of binding for 7 seconds using conventional high melting point flux and the case of binding for 15 seconds using low melting point flux were compared. As a result, reduction of lifespan by thermal impact due to rapid temperature increase and cooling in binding process for 7 seconds using high melting point flux was suspected and the fine binder elution and firmness of build-up edge in 15 seconds of binding process using low melting point flux was confirmed.

The Figure 15 shows the PCD surface after binding process of 7 seconds welding with high melting point flux and the Figure 16 shows the PCD surface after binding process for 15 seconds welding with low melting point flux. As shown in the figures, the binding elution was minimized under the low melting point flux.

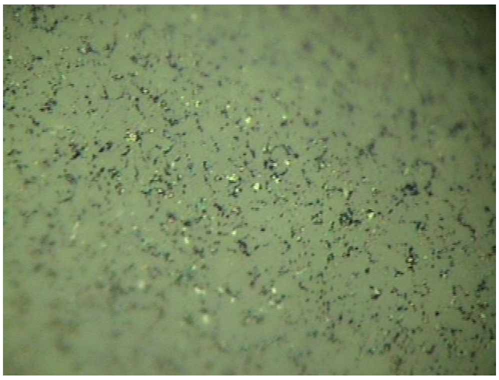

Figure 15. PCD surface after 7 seconds of welding time with high melting point flux

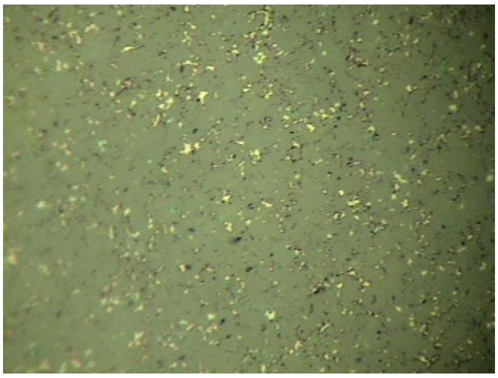

Figure 16. PCD surface after 15 seconds of welding time with low melting point flux

The cause of binder elution from WEDM process, grinding and binding of PCD was confirmed and the improvement effect was confirmed as well. The Figure 17 shows the PCD bite build-up edge prior to process improvement and the Figure 18 shows the final PCD bite build-up edge after binder elution improvement. After process improvement, minimization of poor surface by WEDM process and degree of build-up edge surface were confirmed.

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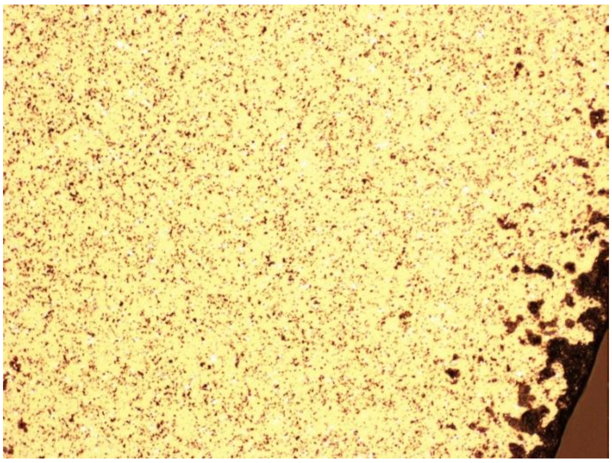


Figure 17. PCD bite build-up edge prior to process improvement

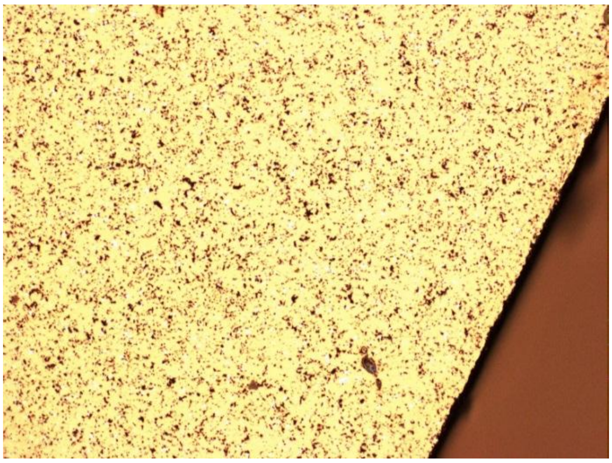


Figure 18. PCD bite build-up edge after process improvement

In binding of PCD and shank for better productivity of PCD tools, vacuum brazing binding using filler metal is generally used. Even in case of perfect mixing through agitation of mixed metal alloys instead of solid solution, there may be separation by components. Moreover, there were grain forms and air voids without melting when the temperature condition was not proper under the composition of filer metal.The Figure 19 shows the poor case of binding section due to improper vacuum brazing conditions.

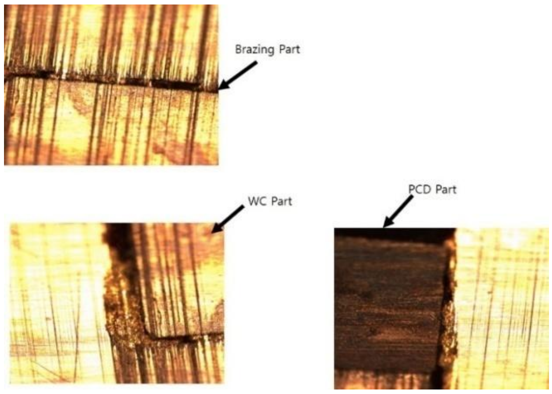
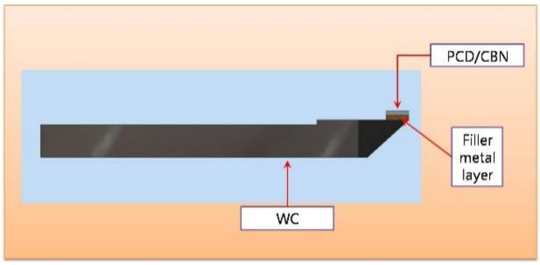


Figure 19. Case of poor vacuum brazing

In this study, only the temperature condition among vacuum brazing conditions was changed to check the trend. The Table 1 shows the conditions for vacuum brazing of PCD and shank.

Table 1. Brazing condition

Type	Condition	Remark
Tip Material	PCD	
Shank Material	WC	
Filler Metal	Ag-Cu-Ti	
Brazing Temperature	500℃, 600℃, 700℃	
Brazing Time	5[min], 10[min], 15[min]	
Cooling Time	5[min], 10[min], 15[min]	

The Figure 20 shows the graph of temperature control under the final temperature raising of 770℃

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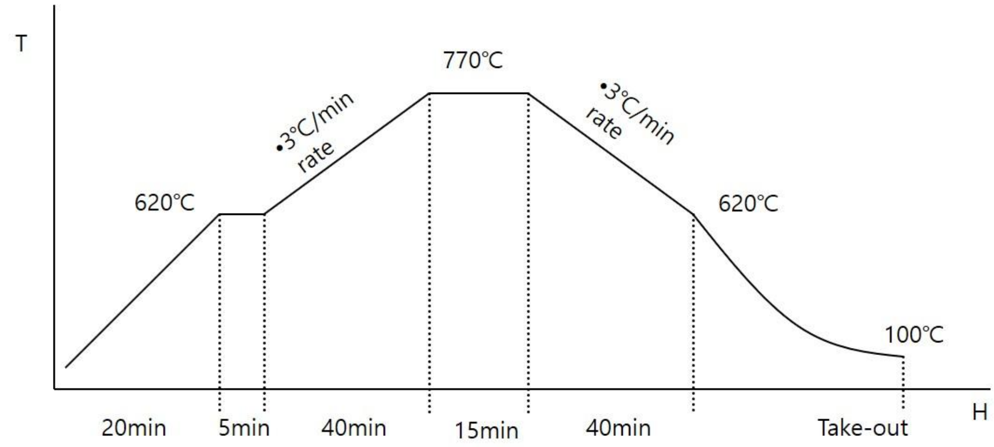

Figure 20. Graph of pattern under temperature of 770℃

The Figure 21 shows the PCD tool surface after vacuum brazing under the above temperature. As shown in the figure, the PCD surface under high temperature could be checked. The result of deflective strength test of binding section was 234[N/mm^2].

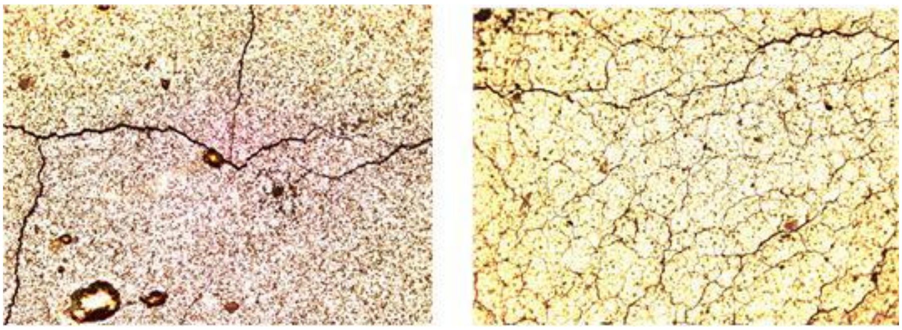

Figure 21. PCD surface under 770℃(poor)

The Figure 22 shows the pattern with the setting of lowering the final heating temperature to be 690℃. Compare to the graph on the Figure 20 above, the same pattern conditions were set except for the final heating temperature.

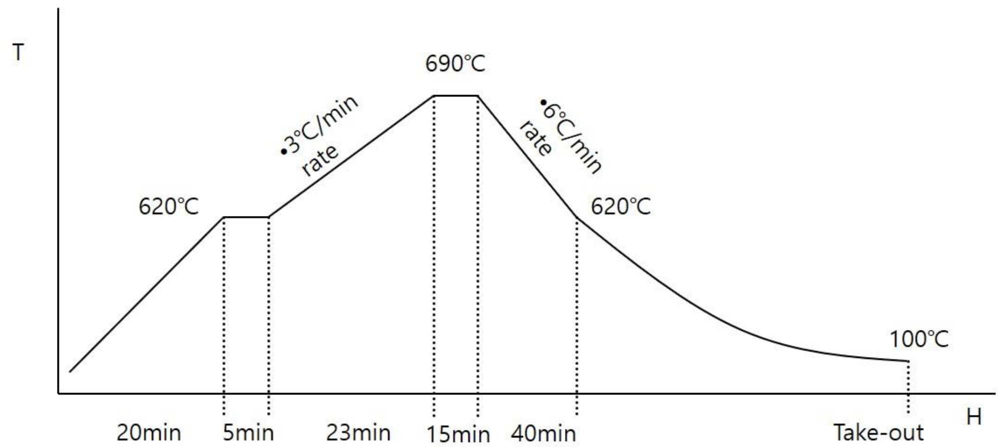

Figure 22. Graph of pattern under temperature of 690℃

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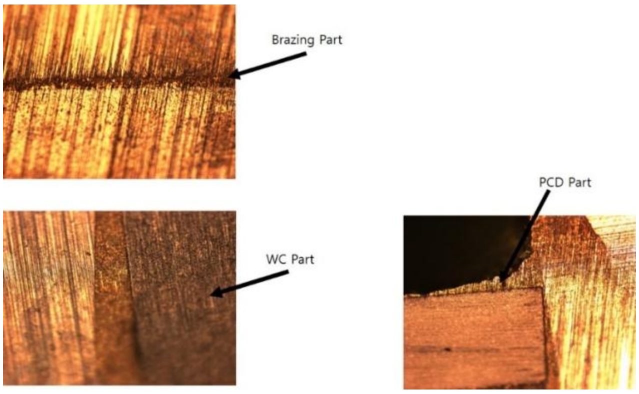

Figure 23. PCD surface under 690℃(fine)

The Figure 23 shows the image of PCD binding section with vacuum brazing by applying the temperature pattern with the final heating temperature of 690℃. As shown in the figure, the melting status of filler metal of binding section is fine. Furthermore, the result of the deflective strength test of binding section 430[N/mm^2], enabling to check the enhanced binding section performance.The Table 2 shows the result of deflective strength test under brazing conditions

Table 2. Deflective force under brazing condition

Type	Condition 1	Condition 2
Temperature	770℃	690℃
Deflective Strength	234[N/mm^2]	430[N/mm^2]
Result	Poor	Fine

Additionally, as a result of analyzing the composition of filler metal in use to check the brazing conditions the composition was Ag 60%, Cu 40% and small portion of Ti. In the composition of metallic structural analysis on the Figure 24, it was confirmed that it could not be in a liquid form under the temperature below 810℃. Moreover, it was confirmed that the structure was not one solid solution but was a mixture of separate components and without perfect combination, the application ratio of each component changed. After a certain time Ti floating on fraction was also confirmed.

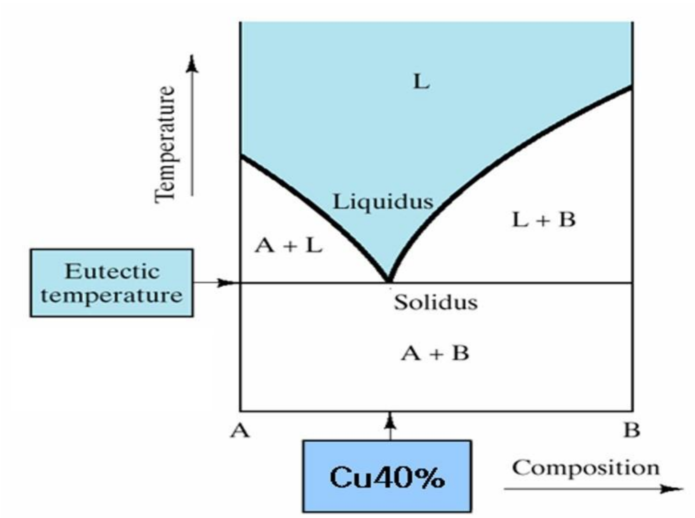

Figure 24. Ag-Cu state

Therefore, to resolve such issue the selection of filler metal of one solid solution made of Ag-Cu-Ti is required. As a result of checking with conditional changes if the cooling time and brazing was 15[min] the most stable binding status was obtained.

IV. Conclusion

In this study, the improvement was performed to check the cause of binder elution from binder grinding and binding process in the WEDM process for PCD machining.It was confirmed that cobalt or a binder of PCD was eluded due to various causes like electrolyte, grinding solution, electrical condition and temperature condition. It was also confirmed that it is important to restraint chemical reactions by reducing direct contact to

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electrolyte to minimize the binder elution.

In vacuum brazing of PCD and shank, significance of the maximum heating temperature condition and the temperature pattern was determined and the proper conditions should be selected to maintain stability and deflective strength of binding status of binding section as the melting temperature condition is different under compositions of filler metal.If the minimization of binder elution of PCD and selection of filler metal mentioned in this study are applied, it is expected that a PCD tool of excellent performance may be manufactured.

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