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Research paper

A Study on Prevention of Binder Elution to Improve Lifespan of PCD Tools and on Improvement of Bond Strength of Vacuum Brazing

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Abstract

Background/Objectives: Process improvement of vacuum brazing and WEDM(Wire electric discharge machining) for improvement of lifespan of PCD(Polycrystalline diamond) tools.
Methods/Statistical analysis: Comparison of the binder elution level under the exposure level of electrolyte in WEDM process for shape machining of PCD plate and measurement of the deflective strength of binding section and melting level of filler metal under vacuum brazing conditions.
Findings: The level of binder elution under the exposure level of electrolyte in WEDM process for shape machining of PCD plate was compared and analyzed and the data were acquired through the deflective strength test of binding section under the temperature of vacuum brazing. The binder elution of over 70% was confirmed after precipitation of PCD plate into electrolyte for about 10 minutes. With respect to vacuum brazing process, the deflective strength test of PCD binding section after completion of brazing under the maximum heating temperature of 690℃ had the outcome of 430[N/㎟].
Improvements/Applications: The binder elution level under the exposure level of electrolyte of PCD plate was confirmed and through the setting of proper temperature on filler metal in vacuum brazing, the improvement of deflective strength of binding section was confirmed. It may be applied to manufacturing processes of various rotating tools like drill, end mill, cutting tool, etc.

Keywords: *PCD(Polycrystalline Diamond), Binder Elution, WEDM(Wire Electric Discharge Machining), Filler metal, Vacuum Brazing*

1. Introduction

Following industrial development and technological advancement, various materials to be ground have been developed and with the development of industries of transportation like automobiles, the amount of use of tools for processing components is rapidly increasing. Especially, components of devices within transportation like automobiles require high precision and high quality and the lifespan of tools for mass production of components is extremely significant in processing fields[1].Diamond is high hardness, high thermal conductivity, low friction and excellent abrasion resisting quality and it has been used as a material of tools in cutting, polishing and polishing for a long time. Moreover, since diamond may keep an acute build-up edge it is used for a case requiring excellent surface degree and dimensional accuracy especially for cutting of non-metal materials with high abrasive quality and malleable nonferrous alloys[2]. Because monocrystalline diamond is very costly synthetic diamond of PCD(polycrystalline diamond) is used as a material of tools for industrial purposes[3]. PCD is polycrystalline diamond particles blended by using a binder like cobalt under high temperature and high pressure and by compressed-sintering it on the parent material of sintered carbide[4]. To make a PCD tool, a PCD plate should be machined to a shape and WEDM(wire electric discharge machining) is generally used for this shape machining[5]. WEDM uses discontinuous discharge to machine a shape of PCD plate precipitated in electrolyte and here, the elution of cobalt, binder to hold PCD particles and irregular oxidation on cut plane occur[5]. This accelerates deviation of diamond particles to reduce lifespan of tools[6]. To prevent this binder elution of PCD, the WEDM discharging machining conditions should be improved and the exposure level of electrolyte should be minimized[7].

Furthermore, to bind a processed PCD to a shank to make a tool, binding using vacuum brazing is used. For vacuum brazing, brazing filler metal is required to bind PCD and shank and synthetic metal fillers like silver, silver alloys, copper, or copper alloys are used[8]. Synthetic filler metal does not stay in solid solution but in a mixture of each metallic material and if it is not mixed perfectly, an application ratio of each component changes. Particularly, in a certain time after agitation, some metallic materials make layers to be floated and a degree of dissolving may not be appropriate[9]. Moreover, if filler metal is not agitated properly to have poor mixing, there may be high air porosity or air void and many particles between shank and PCD and this may weaken binding force of a binding section. If a temperature is increased excessively for better melting of filler metal, excessive heat may damage a PCD plate[10,11]. Hence, this study is to prevent binder elution from exposure of PCD to electrolyte in WEDM process and to select a proper temperature condition for filler metal in vacuum brazing to improve binding strength of binding section for better reliability of tools with higher lifespan of PCD tools. The Figure 1 shows PCD tools.

Figure 1: PCD Tools

2. 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.

Figure 2: PCD Blank

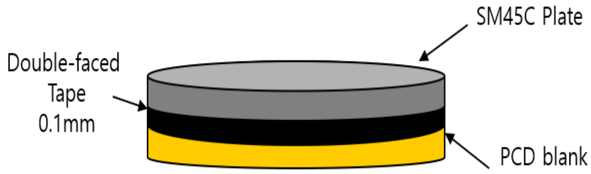


Figure 3: Image of PCD with Sample to Prevent Exposure to Electrolyte

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.

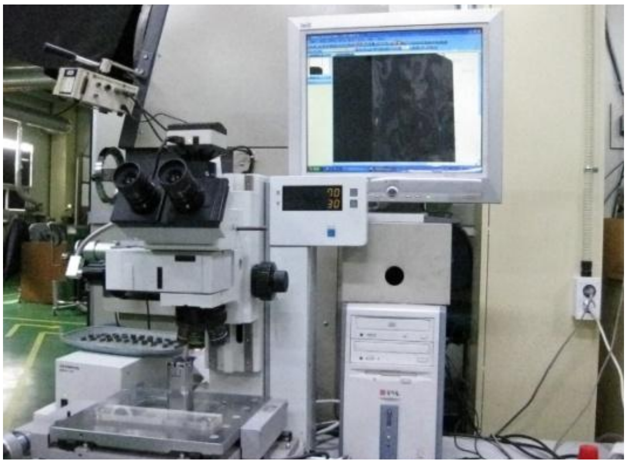


Figure 4: Toolmaker's Microscope(STM-6)

Figure 5: Vacuum Brazing Machine

3. 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.

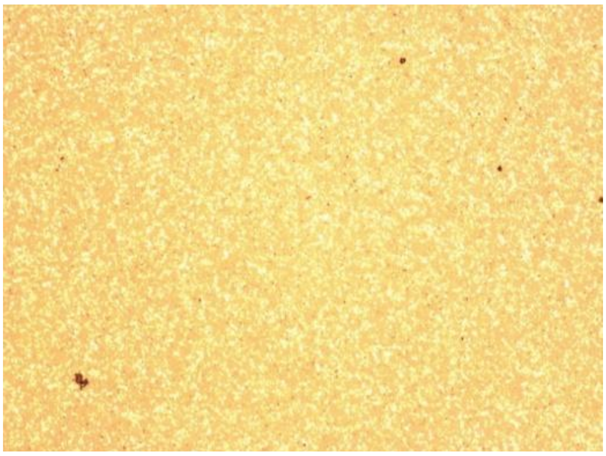


Figure 6: PCD Blank Surface (x200)

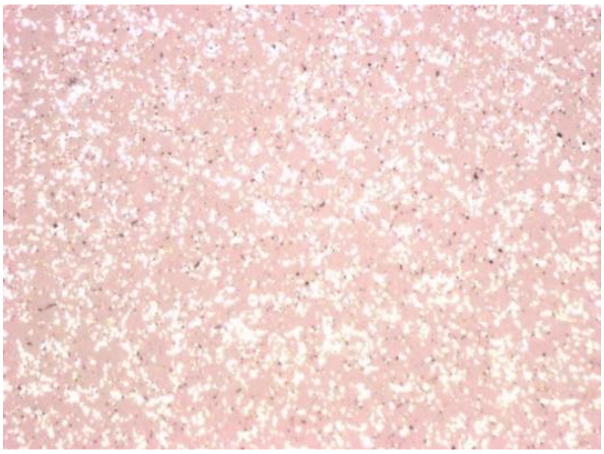


Figure 7: PCD Blank Surface (x500)

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)

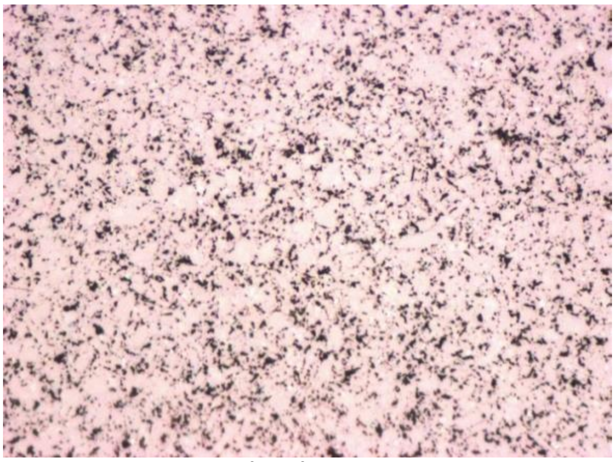


Figure 9: PCD Surface after WEDM Process (x500)

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.

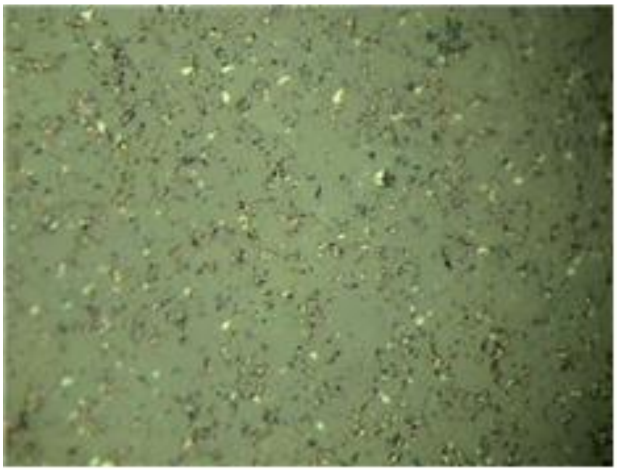


Figure 10: WEDM Process PCD Surface after Changing Electric Condition and Electrolyte Condition

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.

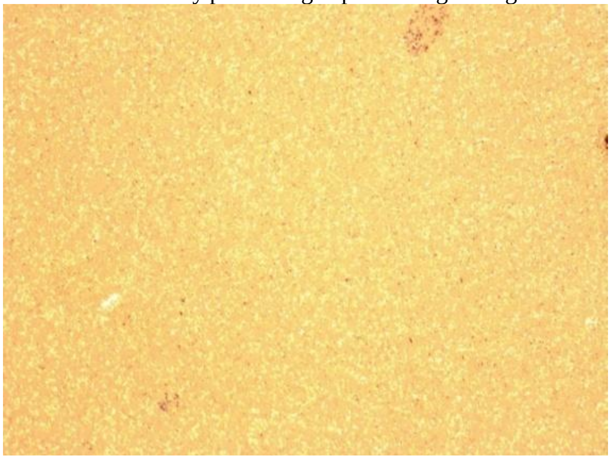


Figure 11: WEDM Process PCD Surface with Agent Preventing Electrolyte Exposure (x200)

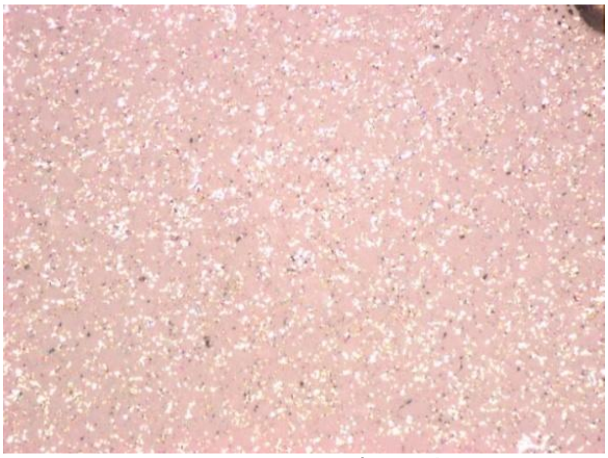


Figure 12: WEDM Process PCD Surface with Agent Preventing Electrolyte Exposure (x500)

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 is required. In this study, the exclusive jig and working platform were installed to minimize the exposure time to conventional grinding solution.

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.

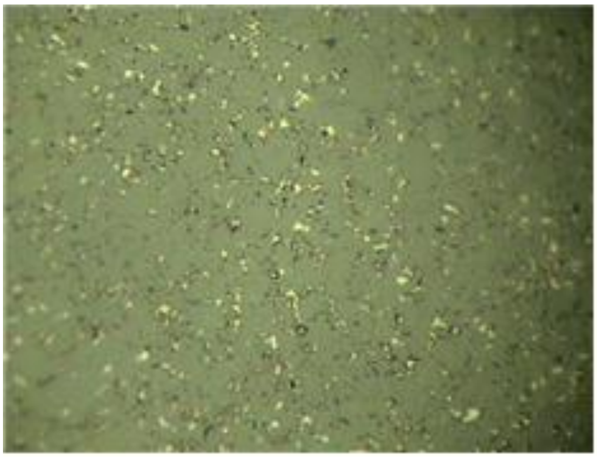


Figure 13: PCD Surface prior to Exposure to Grinding Solution

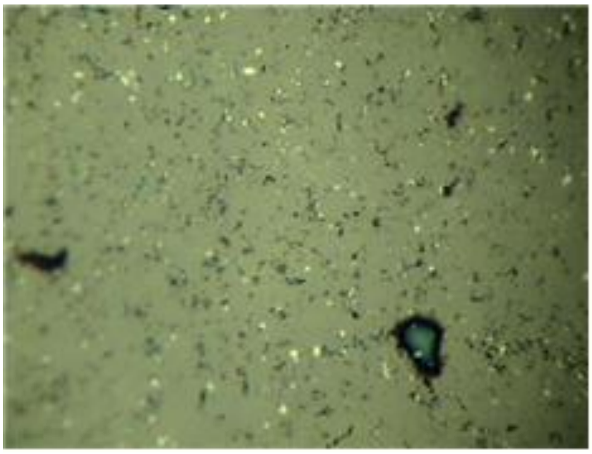


Figure 14: PCD Surface after 10 Minutes of Exposure to Grinding Solution

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.

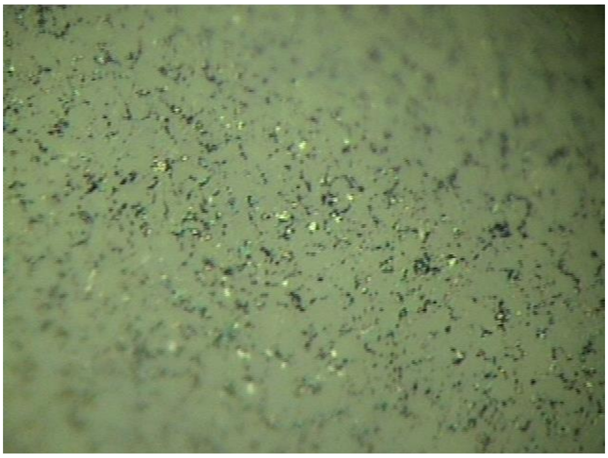


Figure 15: PCD Surface after 7 Seconds of Welding Time with High Melting Point Flux

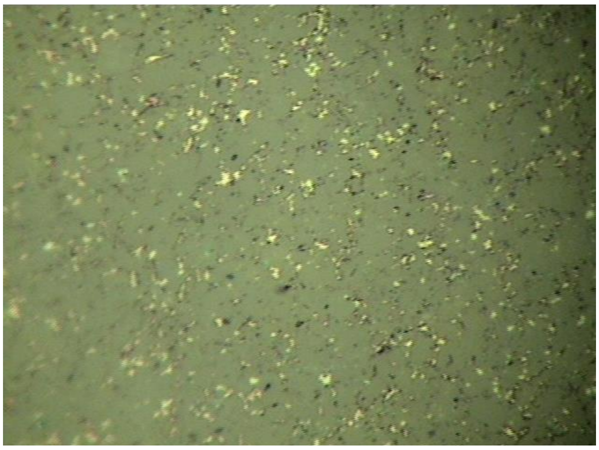


Figure 16: PCD Surface after 15 seconds of Welding Time with Low Melting Point Flux

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.

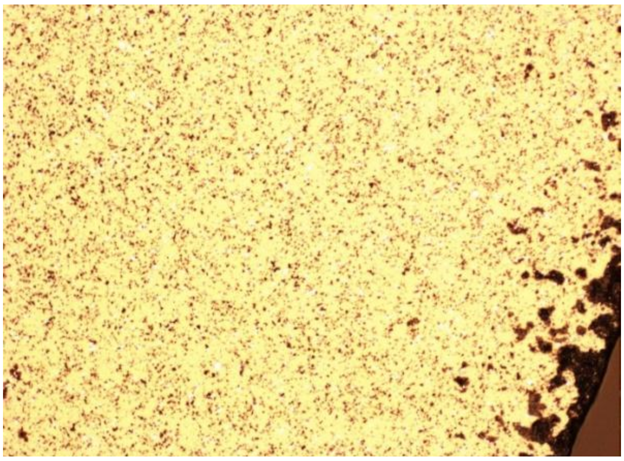


Figure 17: PCD Bite Build-up Edge prior to Process Improvement

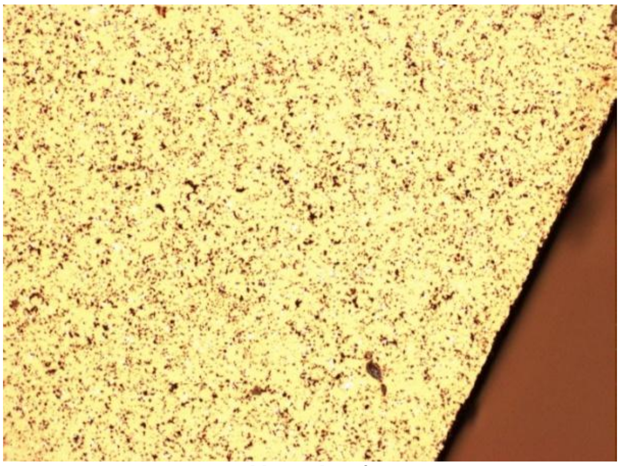


Figure 18: PCD Bite Build-up Edge after Process Improvement

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.

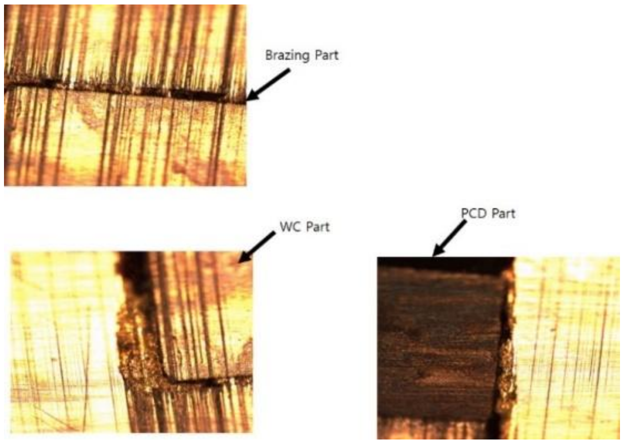
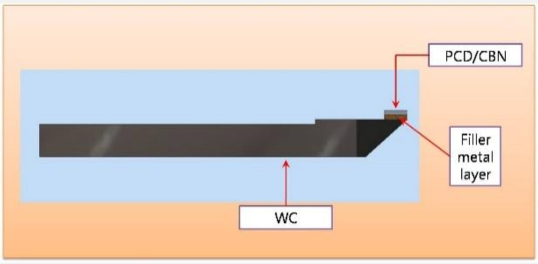


Figure 19: Case of Poor Vacuum Brazing

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 Conditions

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℃.

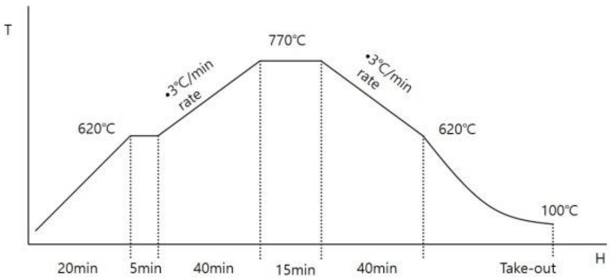


Figure 20: Graph of Pattern under Temperature of 770℃

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/㎟].

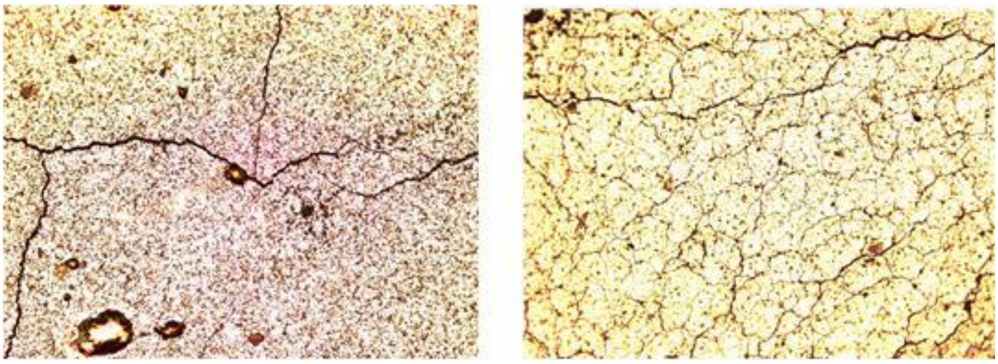


Figure 21: PCD Surface under 770℃ (Poor)

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.

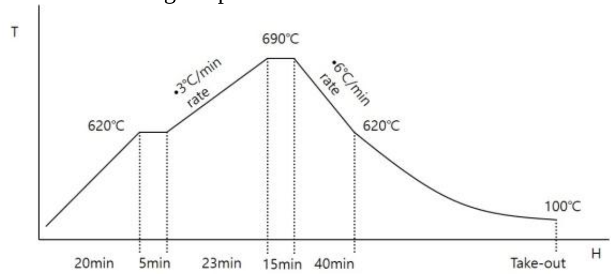


Figure 22: Graph of Pattern under Temperature of 690℃

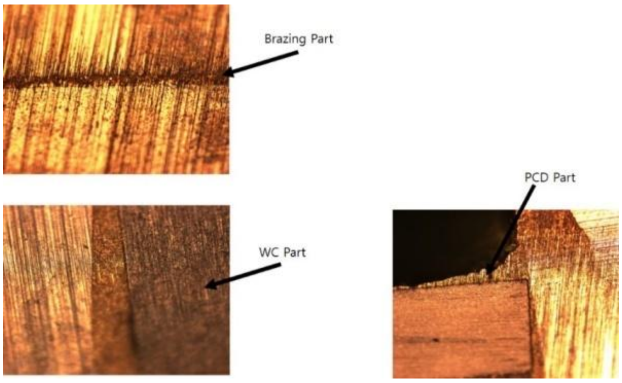


Figure 23: PCD Binding Section under 690℃ (Fine**)**

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/㎟], 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 Conditions

Type	Condition 1	Condition 2
Temperature	770℃	690℃
Deflective Strength	234[N/㎟]	430[N/㎟]
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.

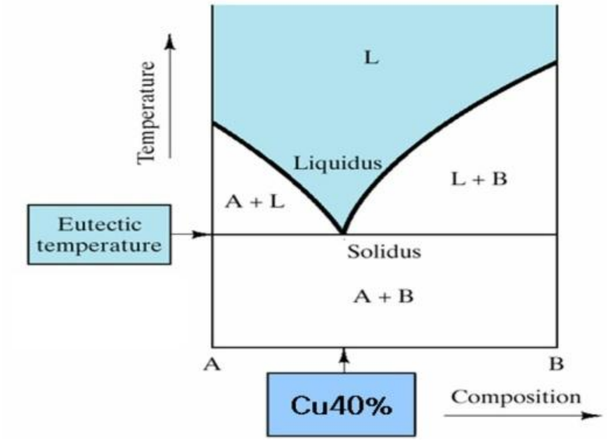


Figure 24: Ag-Cu State

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.

4. 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 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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