Active Brazing of Diamonds – Technology and Application

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Single layer diamond tools are a common standard in the diamond tool industry. In most cases they are produced by electro plating whereas Nickel is used as deposited metal. As there is no joining process between the electro plated metal and the diamond grit, the diamond retention comes only from mechanical fixing by covering the diamonds by more than 50% of their diameter. Active brazing of diamonds is a highly interesting alternative to electro plating. It shows similar advantages like electro plating and additionally it has by far higher diamond retention and therefore a higher life. The following article deals with the active brazing technology, the different metal systems for brazing and the broad band of application possibilities.

1. Introduction

The ISO definition of brazing is [1]: “Brazing is a joining process in which a molten filler material is used that has a lower liquidus temperature than the solidus temperature of the parent material, which wets the surface of the heated parent material and which, during or after heating, is drawn into the narrow gap between the components being joint.”

Brazing of two metallic work pieces is relatively easy in terms of process and in terms of equipment as well. The market offers a huge quantity of different filler metals for all purposes and applications. Diamond however is a material with a covalent atomic bonding structure, which is hardly wetted by most metallic filler metals but wetting is the prerequisite for a good joining process. Brazing of diamond requires a technology which is called active brazing and which is well known in literature for diamonds and for ceramics as well [2], [3], [4]. Using active filler metals is known since middle of the 1940ies [5].

Diamond is a very hard material, but it is also very brittle. Therefore it is quite sensitive to any internal and external tension. The reduction of the thermal residual stress is one of the keys for the whole process to avoid a breakdown of the diamond/filler metal system.

2. Active Brazing Technology

All producers of synthetic diamonds are offering various types of coatings for their diamond grit. Their aim is always to improve the wettability of metallic bonds to diamonds. Without any doubt these coatings are improving the wettability and therefore the diamond retention but they don’t achieve the strong joint of active brazed diamonds.

What does active brazing mean in detail? Adding active metal components to a filler matrix reduces the wetting angle and by reacting of the active metal with the substrate surface a resistant connection, even at higher temperatures, will be the result. Active materials are mainly the carbide forming transition metals from 4th, 5th and 6th group of the periodic table like Ti, Zr, Hf, Cr and others [6]. In case of active brazing of diamonds the strong joint is caused by a carbide reaction. The reaction zone between filler material and substrate has been analyzed by several authors [7] and [8]. Also Kohzaki et al. [9] and Nesladek et al. [10] have analyzed the interface between filler metal and diamond and they could show the existence of TiC formed by the Titanium of the filler material and the Carbon from the diamond.

The difference between an active brazed diamond layer and an electro plated diamond layer is shown in picture 1 and 2. The electro plated diamonds are not fixed by any reaction zone; the retention comes only from mechanical fixing and requires a thickness of the Ni layer of more than 50% of the diamond crystal diameter.
In general two major metal systems are used in active brazing of diamonds: Cu based alloys and Ni based alloys. In case of Cu the alloying elements can be Ag and/or Sn. The active components are mostly Ti or Zr which are forming Titanium carbide (TiC) respectively Zirconium carbide (ZrC). In case of Ni the alloying elements are Si and B. The active component is Cr which mainly forms the carbides Cr$_3$C$_2$ and Cr$_{23}$C$_6$ and to some extends Cr$_7$C$_3$ [11].

Both basic alloy types have advantages and disadvantages. Nickel based filler metal requires in general much higher brazing temperatures. This has an enormous impact. The most critical reason for tool failure is cracking of diamonds. Diamonds are brittle and sensitive to residual stress. Furthermore diamond has a low thermal expansion coefficient $\alpha$ of 1.5 – 4.8 x $10^{-6}$ K$^{-1}$ depending on the temperature level. The thermal expansion coefficient of brazing alloys is about 20 x $10^{-6}$ K$^{-1}$. As a result of the high difference in thermal expansion the diamond surrounding metal layer after brazing is creating high tension onto the diamond crystals during the cooling process. Taking into consideration that the brazing temperature of Nickel based filler metal is about 200°C higher than the brazing temperature of Copper based alloys it is obvious, that Nickel based alloys are creating higher tensions. This results in earlier failure of Ni brazed tools during application.

The higher brazing temperature of Ni based filler material leads to another problem. Diamond starts to suffer from temperature at about 700°C. Three different mechanisms are damaging the diamonds. Damages caused by oxidation and damages caused by graphitization are less dangerous for active brazing. Problematic is the failure caused by micro cracks. This is important especially for synthetic diamonds. Inside of the diamond crystals you find small amounts of metallic residues visible as little black dots. These residues come from the catalyst metals of the high temperature / high pressure diamond synthesis. High temperatures are causing inner tensions inside the diamonds due to the difference in thermal expansion of diamond and catalyst metals like Fe, Ni, and Co. These inner tensions lead to micro cracks which are weakening the diamond crystals. Between 900°C and 1100°C the internal stress caused by these metal residues is doubled. This means that lower brazing temperatures are a clear advantage for the active brazing of diamonds.

Usually the strength of Ni based alloys is rated higher than the strength of Cu based alloys [12]. Documented shear strength for Ag-Cu filler materials are between 120 and 240 MPa [13], [14]. Hull and Malloy found the shear strength of diamond to be 300 MPa [15]. Considering that the strength of the brazing filler metal can be optimized and considering that the strength of diamond drops due to the heat treatment a tool failure during application will be mostly probably on the diamond side and not on the filler material side. This is consistent with the experience of the author of this article.

Table 1 shows a comparison of different types of active filler metal. The major advantage of Ni based brazing alloys is the fact, that the material can be processed under inert gas instead of high vacuum. This makes the process much easier. In literature still a vacuum process is described also for Ni based alloys, because the wetting conditions for the brazing process are better. Comparing advantages and disadvantages of the various metal systems the system Cu-Sn-Ti is technically and economically the first choice to produce active brazed diamond tools.

Diamond tools have a wide application range in the industry. This requires a huge variety of different shapes and geometries of the tools. Opposite to the most technologies described in literature, where the usage of metal foil is recommended, it is by far easier to use metal paste.
The metal paste allows perfect automation using three-axis robot systems to apply the paste onto different shaped steel bodies and gives a better degree of freedom to vary the filler metal composition.

3. Application of Active brazed Diamond Tools
In the following different application examples of active brazed diamond tools will be presented to show the wide range of usage.

3.1 Dressing Tools
Active brazing of single point dressers has a long tradition and is state of the art in the diamond tool industry. The reason is that it does not require a high level of technology to apply the brazing filler metals, which can be either metal foil or metal paste or metal powder. As soon as it comes to larger areas which need to be covered with diamond grit a more sophisticated technology is required to keep the manual work load as low as possible.

<table>
<thead>
<tr>
<th>Design</th>
<th>Sintered</th>
<th>Electro plated</th>
<th>El. plated special</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond grain size</td>
<td>28/30#</td>
<td>28/30#</td>
<td>28/30#</td>
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<tr>
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<td>natural, blocky</td>
<td>natural, blocky</td>
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<td>14 dm³</td>
<td>21.1 dm³</td>
</tr>
<tr>
<td>Specific removal, referred to 1ct of diamond</td>
<td>14 dm³/ct</td>
<td>17.5 dm³/ct</td>
<td>26.4 dm³/ct</td>
</tr>
</tbody>
</table>

Table 2: Life of electro plated single crystal dresser vs. sintered version [16]

In this field another non-rotating dressing tool is more interesting: Single crystal dressers.
These tools are usually sintered. Borse [16] has developed an electro plated single crystal dresser with remarkable results. Borse noted that the bonding of the crystals needs to be improved. He achieved this effect by a thermal treatment of the crystals by creating pockets and holes in the diamond surface. This treatment enlarged the crystal surface and the pockets enabled also a mechanical grip. This increased the tool life by almost 90% (Table 2). The key of the patent is the complex thermal diamond treatment of the diamonds combined with the galvanic tool design. Using instead of the thermal treatment the vacuum active brazing technology the outstanding tool performance could be achieved at much lower cost. Picture 3 shows the differences in design of a sintered standard dresser and a vacuum brazed tool.

3.2 Finger Millers and Profiling Wheels
Diamond tools with a profiled surface require a complex sinter technology or they are electro plated.

Active brazing is a cost efficient alternative. Tests have proven its superior quality regarding performance and life. Picture 3 shows, as an example, a marble milling tool with active brazed diamonds.

3.3 Sandblasting Roller
Marble tiles for outdoor usage are too slippery if their surface is polished. Therefore the surface becomes roughened with bush hammering systems. Bush hammers are creating relatively coarse surfaces. For finer surfaces the tiles need to be sandblasted or nowadays treated with so called sandblasting rollers (Picture 4). The usage of sandblasting rollers has the advantage that the tiles don’t need to be handled twice to put them in a sandblasting device, the polishing heads inside of a tile polishing line become substituted by an active brazed sandblasting roller plate.

This procedure saves handling cost and guarantees a constant and equal appearance of the roughened surface.

1 Picture 4: Weha Ludwig Werwein GmbH, Königsbrunn, Germany
3.4 Circular Saws
Hagan [17] patented in 1999 a tool design for usage for example in circular saw. The knurled design covered with active brazed diamonds simulates a diamond multilayer. Small blades have been used for floor cutting of concrete with remarkable results, especially on heavily reinforced concrete.

The brazing process for complete circular saws with larger diameter is limited by the furnace size. This problem can be solved by producing active brazed segments only.

The segments have a steel body which will be joined with the steel center after brazing by laser welding. Standard inductive brazing of the segments fails because the active filler metal looses its hardness during high temperature treatments due to phase transformation of the Cu based brazing alloy, see picture 5 and 6. The laser welding temperature is higher than the brazing temperature but the exposure time is extremely short, so that the micro structure of the filler metal is not influenced.

3.5 Wire Saw
The most promising application, especially for the near future is certainly the wire for stone and construction. The active brazing technology demonstrates also here outstanding tool performances and applications which, in some cases, can not be solved with other diamond tools.

3.5.1 Application on Calcareous Stone and Construction
Picture 7 shows a spring assembled wire for application on calcareous stone like limestone or marble. Wires for quarries and for stationary machines as well as have proven its performance and they are state of the art in the diamond tool industry. Comparisons in application on stationary machines have shown that the wire with active brazed beads is about 30% faster than a sintered wire and 5-10% faster than an electro plated wire. Compared to an electro plated wire the active brazed wire has about 20% more life.
Also on heavily reinforced concrete these wires are indispensable. Time is very often the determining factor in construction business. Wires with active brazed beads are in general about 20% faster compared to wires with sintered beads. Wires for construction applications are then assembled with springs and additional plastification or plastificated without springs.

3.5.2 Application on Special Structures
Special structures are sandwich materials or special materials like cast iron. Beside the common applications and well known applications for diamond wires new demands have an enormous market potential. Germany has decided to step out of their nuclear power plants. Other countries will follow soon. Worldwide about 120 nuclear power plants need to be demolished within the next 20 years [18]. Engineers worldwide are looking for the best methods to cut for example the extremely strong reactor pressure vessel, which has a thickness of more than 20cm of ferritic steel (22 NiMoCr 3 7, 20 MnMoNi 5 5). Tests with sintered, electro plated and vacuum brazed wires have shown that the vacuum brazed wire is the only one which is able cut this material continuously.

A further new application is the decommissioning of offshore oil and gas installations. Worldwide more than 7000 installations are in place [19]. In Europe are existing more than 600 offshore platforms (Picture 8).

Worldwide 15 to 25 installations are expected to be demolished annually during the next 15 to 25 years and additional several thousand kilometres of pipelines.
Picture 9 shows another example. With an active brazed wire a nodular-graphite cast iron pipe has been cut [18]. The down feet was 20-40 cm/h and the wire achieved a life of 0.6-1.2 m²/h.

The wire has also in the ship decommissioning business proven its fantastic performance. 2.7% of the gross register tons of ships existing worldwide are abandoned annually [18]. These are about 1500 ships. Many of these ships are demolished with an oxyacetylene torch in countries like India or Bangladesh. This job is extremely dangerous for the involved workers. Picture 10 shows a complete wire cut through a freighter.

The possible applications for this outstanding wire technology are not finally explored. The shown examples are already representing a huge worldwide business. Considering an investment for the equipment of about 500.000€ and a production of 100m wire per day what represents a bead production of about 4000 pieces per day, the investment is paid back in about two and a half years.

4. Summery
Active brazing of diamonds is a proven technology since many years. Various metal filler alloys are used for it. For temperature reasons and temperature forced residual stress the Cu-Sn-Ti alloys have found to give the best results considering also the price. Assuming modern paste application equipment active brazing is also from an economical standpoint a highly interesting alternative to electro plated diamond tools.
In many examples it could be shown, that the application of active brazed diamond tools is giving outstanding performance compared to sintered tools or electro plated diamond tools. Especially the
wire with active brazed beads offers a huge market potential for actual applications and for new problems in future.

5. Literature


