Brazing Polycrystalline Diamonds (PCDs) in Applications of Cutting Tools: A review

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Abstract. This article surveys all researches which have conducted on polycrystalline diamond (PCDs) cutting tools, with particular consideration to the characteristics and performance of diamond-metal interface. There has been a revolution in industry over the fifty years or so, due to the usageof diamond in numerous applications, because of the special properties of diamond, joining diamonds to various materials by brazing requires much more precision than traditional brazing. Diamond is frequently utilized in cutting tools and workpieces because of its great hardness and wear resistance. Copper base filler & nickel base filler are the two materials that are most frequently used as brazing fillers in diamond brazing. This review describes the properties of diamond, how it interacts with metals and alloys, how it wets them, what influences these interactions, and how practical aspects of diamond joining is. Additionally, an analysis is doneon a number of new brazing alloys, including amorphous Ni-based brazing filler metals.

1 Introduction

Diamond is one of the few decisive factors needful for the overall growth of contemporary civilization, for variety of purposes, including: a significant raising in the efficiency and particularly precision, when industrialization machinery parts; expand oil wells drilling to locations with hard drilling environments & conditions.; making computer chips by improving the cutting of semiconducting materials; creation possible the mechanical treatment of novel materials, such as new graphite & plastics composites, where conventional tools work badly; and so on. High-speeding cutting, the machining of hardened steels, and the use ofsmall quantities of coolants or even dry cutting have resulted to progress of completely novel tooling notion needful new grinding or cutting materials. These materials need to be able to withstand exceptionally extreme mechanical stresses, maintain compositional stability under severe thermalloads, and be highly resistant to chemical attacks when they are in direct contact with the work

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parts. [1-3].

There are five different types of diamond available for use as cutting and abrasive tools. These are listed below [4]:

1- "Natural single- crystal diamonds".
2- "Synthesized single- crystal diamonds".
3- "Polycrystalline diamonds (PCDs) sintered under high-temperature/pressure conditions".
4- "Thick- film chemical- vapor-deposited (CVD) polycrystalline diamondsup to1 mm".
5- "Thin- film chemical- vapor-deposited polycrystalline diamonds < 50μm".

The physical and mechanical properties of these diamond forms are compared in (Table 1).

Table 1. Physical properties of diamonds [1]

Property	Units	Natural single crystal	Synthetic single crystal	Solid PCD*	Layered PCD	CVD diamond films
Density	lb/in. ^{3} g/cm ^{3}	0.127 3.52	0.115 – 0.127 3.20 –3.52	0.123 3.43	0.148 4.12	0.065 – 0.127 1.80 –3.51
Transverse rupture	ksi	2380 – 4700	3130 – 4700	217	174	188
Strength	GPa	16.4–32.4	21.6 –32.4	1.5	1.2	1.3
Compressive strength	Ksi GPa	1260–2390 8.7–16.5	650–840 4.5–5.8	681 4.7	1102 7.6	2320 16.0
Flexure strength	ksi MPa	152 1050	116–203 800–1400	217 1500	58 400	- -
Young's modulus	Ksi GPa	150 724 1040	115 940–134 060 800–925	134 058 925	112 464 776	77 680–171 014 536–1180
Poisson's ratio	—	0.07	0.20	0.086	0.07	—
Knoop hardness	ksi GPa	8260–15 070 57–104	7826–12 170 54–84	7250 50	7250–10 870 50–75	12 320–14 500 85–100
Fracture toughness	ksi × in ^{½} MPa × m$^{1/2}$	3.09 3.40	5.45–9.73 6.0–10.7	6.27 6.90	8.01 8.80	5.90 6.50
Thermal conductivity	Btu/ft × h × °F W/m × K	580–1160 1000–2000	580–1160 1000–2000	69 120	323 560	434–867 750–1500
Coefficient of thermal	x10 $^{-6}$ F $^{-1}$	1.14–2.73	1.14–2.73	2.16	2.39	2.10
Expansion	x10 $^{-6}$ K $^{-1}$	2.0–4.8	2.0–4.8	3.8	4.2	3.7

*Solid thermally stable polycrystalline diamond (PCD) used in mining tools.

Diamond has extremely hardness and superior abrasive performance. The diamond tools have been divided into sawing tools, grinding tools, drilling tools and, other types by several processing methods. Diamond possess the highest hardness & thermal conductivity of any material at room temperature; at this temperature, the diamond crystal's thermal conductivity can be up to five times that of copper. Diamond is best material for cutting and abrasive purposes due to the special both of these features combined, it is not only cut the treated material, but also quickly dissipating the heat generated from the cutting interface, thereby preventing thermal shocks [5].

One of the few shortcomings of diamond crystals is brittleness. They are breaking on impact by cleavage on four (111) planes. However, contemporaneous sintering and CVD technology allows the produce of polycrystalline diamonds (PCDs) with enough toughness for usage in the majority of industrial applications. Due to brazing is involving heat, it is necessary that diamond is metastable under ambient pressures and temperatures conditions. The graphitization of a "single crystal natural diamond", which is the process of return it to a thermodynamically stability carbon structures, begins at

1600°C in a pure inert atmosphere and at 1500°C in vacuum 5.0×10^{-6} torr. Oxygen (O_2) enhances the graphitization of (PCDs); thus, the temperature of graphitization falls to 1200°C in a vacuum of 1.0×10^{-4} torr and to just about 1000°C in air at atmospheric pressures [6-7-8].

The addition which has been also divided into three categories: “resin bonded diamond tools, ceramic bonded diamond tools and metal bonded diamond tools” (including electroplated & sintered diamond tools) by difference of binders. All of them are promoted and used on a large scale in industrial product, which significantly raising the overall level [9- 10].

The metallic coating in electroplating diamond tools only has mechanical embed impact on both diamond abrasive particles & matrix, so which can’t provide appropriate binding forces for both diamond abrasive particles & matrix. The result is the abrasive particles are fallen off easily, and they are disordered with low exposure and chip space. The sintered matrix materials in sintered diamond tools only has the function of mechanical "impregnating and embedding" for diamond, and it is not easy to fulfill the metallurgical combination between both abrasive particles and matrix. After applying force, the abrasive particles are still easily detachable, difficult to edge, and have poor self-sharpening [11].

In order to allow entire playing to the superior performance of (PCDs) itself and indeed changing the problems of deficient controlling force of the matrix on diamond, it is hoped that the solid contact can be carried out through the chemical metallurgical influence between diamond abrasive, the filler metal, & steel matrix. By adding filler metal having strong carbide forming elements such as “Ti, Cr, V”, high-temperature brazing diamond tools can achieve the chemical metallurgical combination of diamond abrasive, filler metal, & steel matrix. This improves the controlling force of the filler metal on diamond, making the diamond abrasive less likely to falling off or come off while grinding process [12-13].

Instead of electroplating, high-temperature brazing is used to prepare diamond tools, which can reduce environmental pollution and meet the demands of green and clean manufacturing in industrial production.

Diamond brazing tools are more efficient in vacuum furnaces, but the heating and cooling rates are slow, increasing the holding period for the diamond throughout the brazing process and making heating and coolingrate management challenging. Active filler brazing diamond tools brazingmechanisms are required for improved physical and chemical brazing interface analysis, diamond brazing process optimization, and less heat damage to diamond in order to provide more excellent brazing diamond tools machining performance [14].

2 Brazing

The term "brazing" includes a group of welding techniques that creates coalescence of materials, when they are heated to the brazing temperature in the existence of filler metal that has a liquids temperatureover 450°C and below solidus temperature of the base metal. (The liquids, or melting point, is minimum temperature at which a metal or an alloy is fully liquid, while the solidus is the maximum temperature at which a metal or an alloy is fully solid). By means of capillary action, brazing filler metal has been spread between the tightly fitting faying surfaces of the brazed joint[15].

Technology known as "brazed diamond technology" is capable of creating a chemical reaction with the abrasive grains of diamond & producing metallurgical fillers with a steel matrix for brazed connections. The interface between diamond and filler is chemically metallurgical because active elements in the filler can chemically reacting with diamond. As a result, the bonding strength is high and the diamond is difficult to falling off from the matrix. As a result of large bonding strength between diamond & matrix leading to a series of benefits of brazed diamond tools[14-16].

– High level of abrasive particle exposure. Because of the high bonding strength, the control strength of the abrasive could satisfy the grinding requirements when thickness of the filler bond layer is kept at 30% of the height of the abrasive. Comparison with another different tools is challenging.
– Sizable chip space. High exposure causes the chip space between the abrasive to grow in size, making it easier for the chip or abrasive chip to successfully discharge from the abrasive particles, which is difficult to cause tool failure due to chip blockage.
– As a result of good efficient heat dissipation, the possibility of burns risk will be reduced. Because of the good chip removal effectively, a lot of amount heat will be taken off via the chip, therefore, the temperature of the workpieces surfaces and also the possibility of the workpieces surfaces being burned surely will be decreased.

3 Brazing of diamond tools

Diamond materials can be brazed in a single stage using active alloys (during melting, these alloys wet the diamond surface and form strong interphase bonds with carbon atoms), or in two stage process where the diamond is first coated with a metallic film "the diamond is metallized" and the brazing process can then be carried out using a typical brazing alloy used for joining metals. The most important key factor in controlling joint performance is the interfacial carbide reaction between the diamond & the braze alloys. Diamond doesn't need highly reactive filler agents to encourage the interfacial interactions, unlike the active brazing of oxide or monoxide ceramics. Diamonds can be successfully wetted by moderately reactive metals like silicon or chromium, whereas high-performance ceramics need refractory metals like zirconium, titanium, or hafnium to cause a wetting reaction [17].

[In 2015, Duan et al] A diamond that have been brazed with brazing filler alloy of (Cu-Sn-Ti). It is found by analyzing the interface between diamond & brazing filler, that elements diffusion has been occurred at interface, and a strong bonding has been formed between the diamond and coating. It was discovered that composite pitch had a higher interfacial bonding strength, and provided better grinding results than traditional diamond pitch [18]. [In 2016 Wang et al] presented a new technology vision, it is a large- grained alloying filler vacuum sintering diamond brazing, and the geometry model has been established, The results of the vacuum brazing diamond sintering test and heavy-load grinding test demonstrate that: the large-grained nickel-based alloy filler melts completely and flows well; the diamond has a good effect of climbing and embedding [19]. [In 2006 Yamazaki & et al] In his investigation, the synthetic diamond can be brazed to the “42 Invar alloy” plates at braze temperature 815°C and time 240 seconds by using brazing filler metal with an “Ag-27.8Cu” system that contains less than 1 mass% vanadium resulting increased the stability of the joint strength (at the brazed interface the shear strength has exceeded 200 MPa). By using lattice misfit data to pick a brazing-filler metal, the composition of an “Ag–Cu–V” system using perturbation interface model has been evaluated, and then it has been applied to braze “Synthesized single-crystal diamond (111)” by method of unidirectional-solidification brazing. At brazed interface that silver crystal grains has grown from islands of (V4C3) which formation on the diamond has been detected through optical observation. This manner is compatible with tenuous degree of lattice misfit between vanadium carbide crystals & silver. The formation of different types of vanadium carbides, including “V8C7, V4C3, V2C”, was revealed by X-ray diffraction results. Due to the preferential solidification of silver on the reaction product islands, V4C3 reaction product has been considered to supply an excellent adhesion between fillers metal & crystals diamond Figure 1 [20].

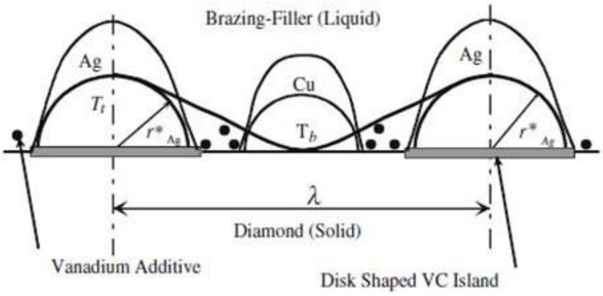

Fig. 1. Ideal model of cross section of diamond boundary joined unidirectional solidification by brazing methods.

4 Design fundamentals and principles of brazing fillers metals

Brazing filler metal for (PCDs) diamond tools must be capable to wetting the diamond particles fully firstly place. in order to select of brazing filler metal must follow the following principles[21]:

- When the melting point (m.p) is low, braze filler metal temperature is also low, which can significantly lessen or even prevent the graphitization of diamond.
- The filler metal's elements can react with carbon atoms to produce compounds, consequently wetting the diamond very well without affecting the functionality of the diamond particles.
- To increase their service life, diamond tools must have superior wear and impact resistance.
- Hot cracks are easily generated, due to a quite difference between the brazing and actual operating temperatures. The brazing filler metal and diamond must have the same linear expansion at the same temperature, which helps to prevent the development of hot cracks.
- Under various operatives conditions, the diamond tools surely have different shapes, and the brazing fillers metals must be easily machined into appropriate shapes on the base of suitable machining.
- Precious metals should either be used less or not at all to lower the cost of use. Based on the foregoing, diamond tool brazing typically involves the utilize of three active brazing alloys: Ag- based, Cu-based, and Ni-based.

5 Silver (Ag) based filler

Silver has a lower melting point (m.p) than basic filler metals Nickel and Copper, which makes it one of them with good wetting and spreading properties, and it might be one way to lessen the reactivity. Practical production has made extensive use of the brazing alloy fillers “Ag-Cu-Ti” & (Ag-Cu-Cr). Due to low liquids temperature of (Ag-Cu-Ti) brazing filler alloy, could be avoided diamond conversion into graphite. In addition to having a low liquids temperature, the (Ag-Cu-Ti) alloy has high ductility, which helps to prevent crack forming at the diamond-filler interface. Additionally, the active element titanium Ti possess the ability to react with the carbon in diamond to generate TiC, and the Ag-Cu-Ti filler has strong wettability to diamond. Filler can melt at temperatures more900°C; the melting point is low. due to (Ag-Cu) brazing filler metal is a highly plastic material, the brazing stress can be released & improved the joints strength. However, because it is a valuable metal, using Ag is relatively expensive [22].

[In 2019 Mukhopadhyay & et al] has studied the effects of micro/nano- Al_2O_3 ceramic particles, when titanium Ti activated “72Ag-28Cu” brazing filler alloy was strengthened with these particles. The results have shown, that the diamond abrasive has an excellent exposure height, the interface between both the abrasive and the filler is clearly, the crystals shapes of abrasive grains are perfect after brazing process, and there are free obviously from cracks, impurities, graphitization, and others phenomena on the abrasive's surface as depicted in Figure 2 [23].

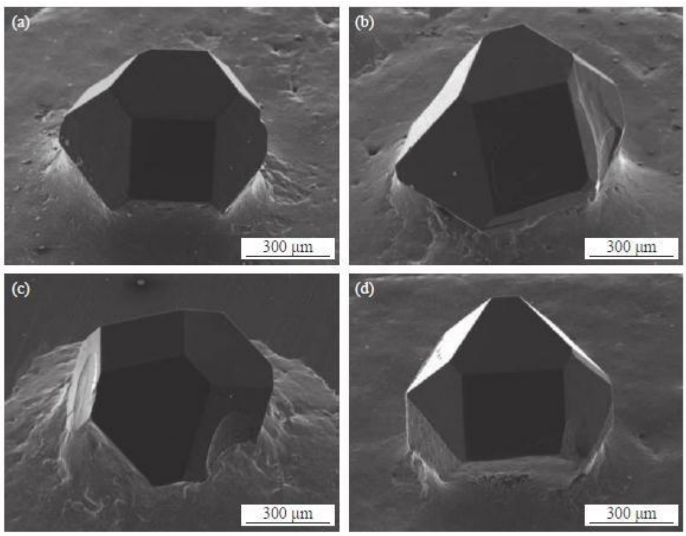

Fig. 2. Showed diamond brazing with” Ag-Cu-5Ti” filler alloy that has been strengthened with (a) 1 wt% nano- alumina (b) 2 wt% nano-alumina (c)1wt% micro-alumina and (d) 2 wt% micro-alumina.

[In 2017 Zhang & et al] has studied the distribution of elements Ag, Cu, Ti & Fe at interface as shown in Figure 3, which exhibits a transition trend, and the concentrations gradient shifts a little. In the silver-rich area, the amount of copper is quite low. Identically, in the enrichment region of copper element, the content of silver element is quite small, and the two elements are essentially complement. On the one side of the steel substrate, there are very clearly vision that Ti and Cu atoms on the bias diffusion, due to that Ti, Cu and Fe elements have the same periodic element, and their atomic radius & properties are identical so the existence of Ti atoms in the area far away from the brazing interface is rarely, however the diffusion phenomenon is obviously quietly between the brazing filler alloy& steel substrate, leading to create a metallurgical bonding [24].

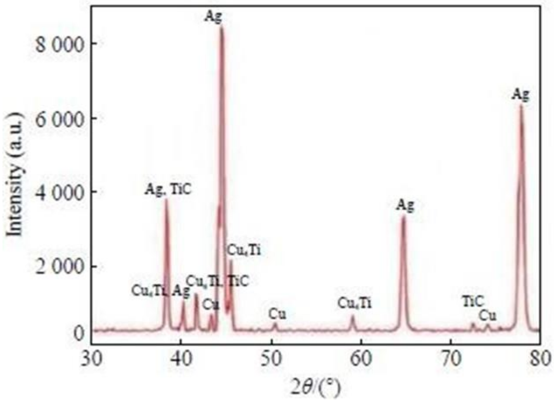

Fig. 3. X-Ray Diffraction of the interfacial phases of brazed diamond.

[In 2017 Mukhopadhyay & et al] has studied joints strength and interfacial chemistry of synthetic single-crystal diamonds brazed with "Ni-Cr-B-Si- Fe" & "Ti activated Ag-Cu" brazing filler alloys, as according to his study has declared that "Ti-activated Ag-Cu" brazing filler alloys are substantially softer than "Ni-Cr" alloy, and there was no such crack has revealed in the case of "Ag-Cu-Ti" brazing filler alloy & the joints has been missed by ductile fracture of alloy close to interface, resulting may have been the diamond to be drop-out. The peaks corresponding to titanium carbide may be found in active silver-copper based brazed joints. The reaction (1) illustrates the reaction mechanism for the creation of titanium carbide compound [25-26].

At temperature about 820°C, Gibbs free energy forming of this compound (TiC) is about (−175 kJ/mol).

$$Ti + C \rightarrow TiC \quad (1)$$

[In 2014 Basri & et al] has investigated the effect addition of tin on liquids & solidus temperatures and gap filling ability of the ternary “Ag–Cu–Sn” alloys on copper. Microstructure and shear strength of the joints have been examined and according to ISO 5179-1983, a gap-filling ability test procedures investigation was carried out. The outcome of the differential thermal analysis revealed that when tin content in “Ag-Cu-Sn” raise, the filler metals solidus and liquids temperatures decreased, as well as the brazed joint had the highest strength at a 10 weight percent tin concentration in the filler metal according to the shear test findings. Gap size was correlated with the capillary rise height. The amount of tin present, however, has no appreciable effects on the height of the capillaries, when creating the brazed joint for the filler metals “Ag-Cu-Sn”, It was recommended that joint gaps be fewer than 0.10 mm. [27].

6 Copper(Cu) based filler

Cu-based alloy fillers have been mainly divided into "Cu-Sn-Ti" and "Cu-Sn-Zr-Ti". Accordance to the Cu-C phase diagram [28], that the element C in Cu is highly insoluble, which decreases the erosion of diamond by brazing filler metal. Sn element can be added to the alloy torise strength of the filler layer & lower melting point of the Cu-based filler by forming intermetallic compounds with Cu. Sn element can be added to the alloy to increase the strength of the filler layer and lower the melting point of the Cu-based filler by forming intermetallic compounds with Cu.

When compared to Ni-based filler, filler melting temperature is low, and diamond grits thermal damage is minimal, and the active element Ti can achieve with diamond grains metallurgically reaction, leading to get betterthe bonding strength of both diamond particles & filler, but layer of Cu- based filler alloy brazing with poor wear resistance and low hardness, leading to get greater losing the whole of the diamond grains, resulting inthe end, the service life of diamond tools will be shortened [29].

[In 2012 Buhl &et al] has studied effect of brazing processes on residual stress, matrix structure, & diamond particles strength. when temperature of brazing is about 930°C and the heat was preserved for 10 minutes, a generation of a large amount of (Cu, Sn) embedded intermetallic phasehave been found, and the residual compressive stress after brazing the diamond particles is 350 MPa. At temperature range of (880 to 980) °C, shear strength decreases as brazing temperature & heat preservation timerise. [30].

[In 2002 WEN-CHUNG LI & et al] has studies brazing surfaces of diamond grits & steel substrate by use pre-alloyed (Cu-10Sn-15Ti) at temperatures 925°C and 1050°C. The braze matrix revealed a composite structure made up of β - (Cu, Sn), Cu-based solid solution (ss), and different intermetallic compounds with various morphologies because of the comparatively high concentration of Ti in the brazing alloy. On the surfaces of the diamond grits, a continuous layer of TiC has produced by the interaction of Ti with diamond. Intermetallic compound of Sn and Ti has nucleated and grown, takes shape as randomly interwoven fine lacey – structure on top of the TiC growth front. An interfacial-structure grows onto taking shape interwoven fine lacey-phase has semi-coherently bonded to layer of TiC, and its interstices has been filled with a Cu-based brazing matrix Figure 4[31].

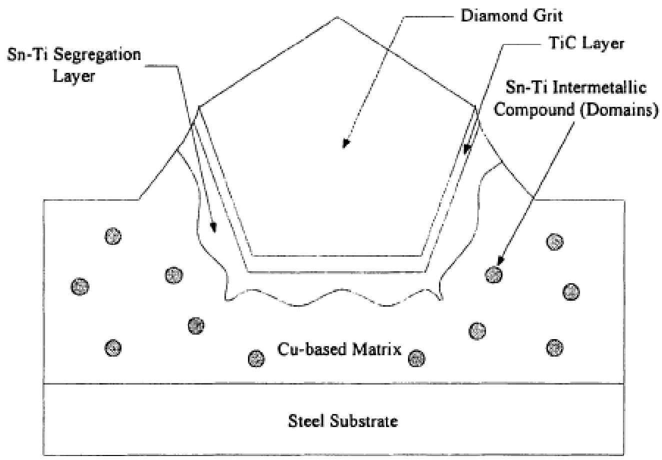

Fig. 4. Structures of the braze matrix & the interaction between the diamond grits and the braze matrix are depicted.

[In 2016 Fu & et al] has carried out the research onto the graphite's surface which has been metallized and brazed using a brazing filler alloy (Cu-Sn) with (Ti) activated element. The results have demonstrated that the wettability of brazing filler alloy (Cu-Sn) with Ti element added is better than that of traditional (Cu-Sn) without Ti element added. TiC compound is formed in the graphite layer and brazing filler alloy. After brazing, many (Cu-Sn) compounds were visible in the filler layer [32].

[In 2014 Ma & et al] has studied "Cu-Sn-Ti" alloy which has been utilized as the brazing filler alloy for producing diamond grinding head. In the interface between both diamond & Cu-based fillers metals a chemical reactions, diffusion, and dissolution has occurred. Cu-based filler metals and steel matrix between them the width of diffusion band is about (30 µm), this indicates a goodness metallurgically bond between both diamond and Cu-based filler metals, as such as Cu-based filler metals and steel matrix Figure 5.

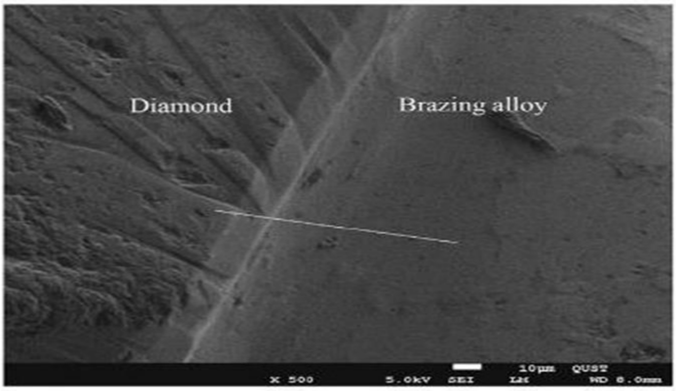

Fig. 5. Shows the microstructure & compositions at interface where brazing alloy and diamond grits are joined.

At interface between both diamond grits & brazing alloy, there is a tendency of Ti and Sn for segregation. TiC reaction layer has been formed as grains shape about 50 nm in size between both diamond grits & braze matrix, can relieve interfacial stress associated, this leading to promote strength of interfacial bonding as depicted in Figure 5 [33]. [In 2008 Klotz & et al] have investigated that reactions which occurred at interface between diamond & active brazing alloy, have a crucial effect in advancing and understanding tools performance, where active brazing alloys is an efficient technique to join diamond with metallic substrates. Super abrasive, high–performance tools are currently being made using this technique. As characterization of the interfacial nanostructure, two layers of TiC with various morphologies have formed, the first one, a cuboidal layer appears immediately on diamond & grows to a thickness of roughly 70 nm Figure 6, while the second one containing columnar TiC crystals has grown on the first layer into brazing filler alloys by a process of diffusion-controlled Figure 7. Depending upon on brazing temperature & holding period, combined thickness of two TiC layers can range from (50 to 600)nm. Relative residual stresses resulting from brazing procedure must be saved to a minimum in order to enhance performance & reliability of brazed diamond tools. Phase diagram data indicates that the ideal alloy compositions fall between “Cu-18Sn-6Ti” & “Cu-9Sn-15Ti”. Alternative brazing techniques like induction or laser brazing must be taken into account because the substantially faster processing times will produce thinner TiC layers [34].

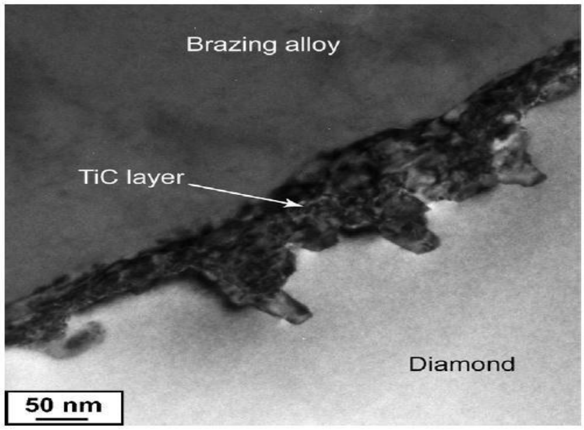

Fig. 6. TEM bright-field picture of the cuboidal TiC layer produced by brazing the "Cu–14.4Sn–10.2Ti–1.5Zr" alloy. at 880 °C/10 minutes.

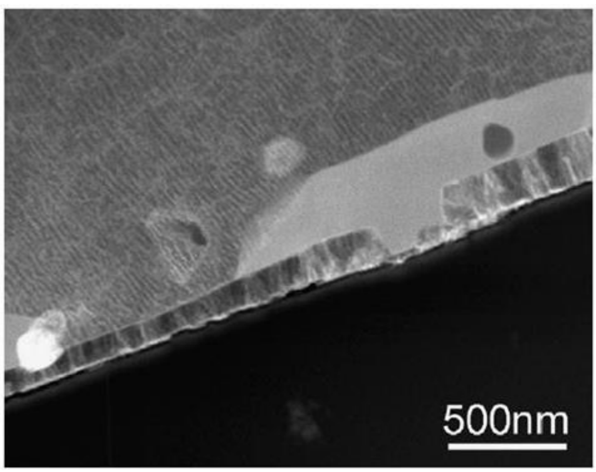

Fig. 7. STEM dark-field image shows interface between a diamond-brazing alloy. TEM bright-field image.

7 Nickel (Ni) based filler

The Ni-based fillers have been used as a functional brazing layer in aerospace devices and other specialized industries, Because of its strong corrosion resistance, high hardness, wear resistance, and environment adaptation to high temperatures. With high hardness, high strength, & high temperature resistance of the Ni-based brazing layer and diamond's extremely high elastic modulus of 1100 GPa, the Ni-based filler alloy can be employed to create diamond tools for drilling , cutting, and grinding working under severe conditions [35]. Ni-Cr based alloys offer better hardness and abrasion resistance than "Ag-Cu-Ti" alloys. "Ni-Cr-P" brazing filler alloy achieves the solid metallurgical bonding combination of steel matrix and diamond buy using high-temperature brazing process under vacuum atmosphere.

The brazing tool advanced has the special characteristics of high level exposure of abrasive, low accumulation of filler layer, during the brazing process, it was discovered that Cr can form a strong carbide in the filler, and can diffused to the diamond interface, in order to metallize the abrasive surface to get a good wetting, nearly there is no abrading phenomenon during working, its service life have a much longer service life than electroplating [36].

Better interface bonding and brazing interface are achieved by using nickel chrome filler (Ni-Cr) on the diamond surface, the braze interface bonding between “Ni-Cr” filler alloy & grits of diamond are illustrated in Figure 8a. It is obviously from the outcomes of the line scanning analysis, which is displayed in Figure. 8b, that the distribution curves of the two elements, C & Cr, at interface between the abrasive & the filler, have changed significantly. This indicates that there was a significant mutual diffusion phenomenon between the two elements in the interface. The Cr in the brazing filler metal layer exhibit clear segregation at the interface, and it is clear that Cr concentration distribution is substantially which close to the abrasive surface attachment is more higher than that in the brazing filler, demonstrating that Cr have been continuously accumulating towards the interface.

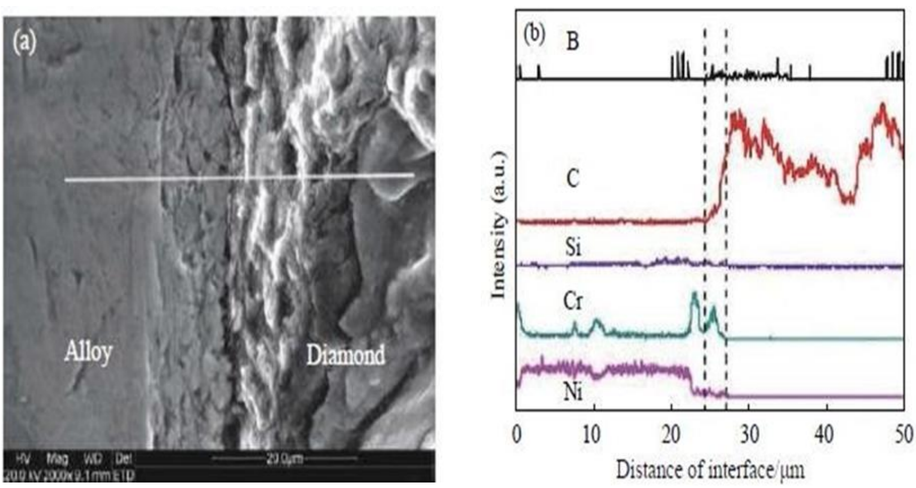

Fig. 8. Shows interface of bonding between diamond abrasive particles and "Ni-Cr" braze filler.

Identically, the element C is also affected segregation phenomenon in the interface layer. There is a concentration gradient in the distribution curve of element C at the interface obviously, and element C diffuses from the brazing filler layer to the abrasive surfaces [37]. The active element within filler metal (Cr) being beside forming a strong carbide, reacts with carbon element (C) at high temperature in the abrasive interface, forming a stable carbides between brazing fillers metal interface and abrasive gradually. As reaction continues between Cr & C elements, Cr element in brazing filler metal continues diffusing to interface until an equilibrium state is reached, resulting in the generation of a rich Cr layer at the interface. The Cr element distribution curve exhibits a noticeable crest at the grain filler interface, as demonstrated by the interfacial element line scanning distribution curve, and this Cr-rich layer region could be the new compound region.

At interface junctions, chemical metallurgical bonding also takes place to strengthen the bond [35-38]. [In 2012 Sun & et al] has studied influence of brazing period onto microstructures of elevated temperature brazed diamond using “Ni-Cr” alloy, the main phases of the brazing filler alloy “Ni-Cr” on the diamond's surfaces have been investigated for various brazing process times. According to XRD results, there are two layers of carbides (Cr3C2 and Cr7C3).

This is depicted in Figure 9. An orientation relationship exists between the entire “Cr3C2” process and the diamond crystallographic plane, and on the surface of carbide layer, “Cr3C2”, carbide layer Cr7C3 is being nucleated as explained Figure10. Morphology of carbide “Cr3C2” changes from linear to lamellar, whereas carbide “Cr7C3” changes from granular to columnar as brazing duration increases. After brazing process, a chemical metallurgical combination between the brazing filler alloy and diamonds has been achieved, and carbides are primarily responsible for the strong binding strength [38].

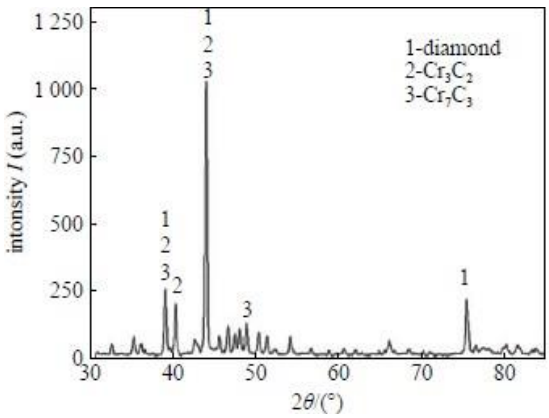

Fig. 9. Shows the X-Ray Diffraction patterns of diamond & carbides.

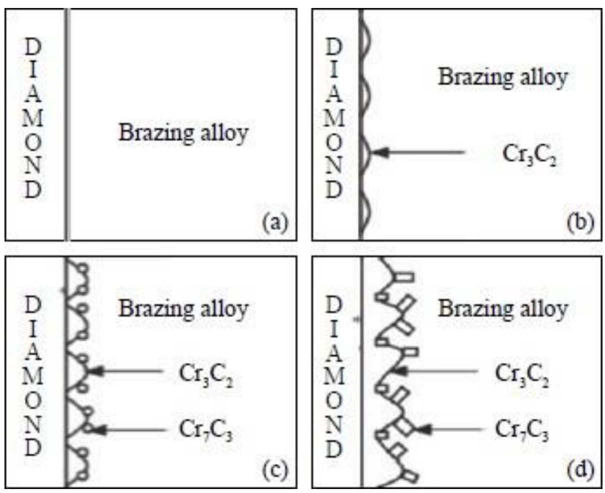

Fig. 10. Formation process of carbides.

[In 2017 Mukhopadhyay & et al] has rigorously examined the inherent challenges of vacuum brazing large-sized D711 synthetic single crystal diamonds with medium carbon steel utilizing a “Ni-Cr-Fe-B-Si” alloy. At a brazing temperature of 1050°C, the alloy shows considerable wetting on diamond; nonetheless, all as-brazed samples show microcracks that are visible at the bond level. Even utilizing a slow cooling rate 5 °C /min does not stop a crack from growing. The substantial variance in the Young's modulus and thermal expansion coefficient of the substrate, alloy, and grit generates unfavorable tensile residual strain on diamond at the bond level, which causes harmful stress. It has been found that the development of microcracks under residual stress seems to be promoted by the formation of a partially coherent phase of chromium iron carbide. Using finite element studies.

At the interface region, the residual stress distribution is mapped. When the cooling rate is slowed down to 50°C/min, there is no discernible variation in the strength of the joints. The grit failure pattern points to a predominance of bond level breakage in diamond grits, which denotes the presence of residual stresses in the bond level. Even in a very high vacuum environment, greater temperatures cause significant graphitization to occur on the (110) crystallographic plane of diamond. [39].

[In 2019 Zaharinie & et al] has investigated the joining diamond grits to stainless steel, an active filler metal such as Ag-Cu-Ti, Ni-Cr, etc. and porous nickel as an interlayer have been used by brazing process. There are three brazing temperatures (880, 920, and 960)°C have been tested for total time 10 minutes for accomplishing brazing process. The porous Ni-stainless steel interface showed good bonding. The findings show that after brazing, the stainless steel and filler metal diffused, and an AgTi2 reaction layer has been formed and crossed along over the brazing layer. At a low temperature (880°C). The reaction layer seems to be continuously forming. However, at 920oC brazing temperature. There will be an increase in reaction layer thickness, and a crack was visible at low magnification as a result of a small voids formation close to the reaction layer. The reaction layer has formed discontinuously at higher temperatures (960°C) because the brazing temperature was so close to the melting point of the silver element (raising Ag liquidity).

It was not anticipated that the produced Ag-Ti phase would weaken joints or be very brittle. Reducing the creation of this reaction layer is advised in order to enhance the bonding performance. According to this study, brazing at 960oC was more effective for strong bonding [40]. [In 2008 Yang & et al] have conducted research on the utilization of a laser beam and an argon environment to braze diamond grits onto a steel substrate using a Ni-based filler alloy "Ni-Cr-B-Si". Steel substrates and diamond grains were well-wetted by "Ni-Cr" alloy during the laser brazing process. The chromium (Cr) in the Ni-based alloy was concentrated at the surface of the diamond grains, in the interfacial reaction region between the diamond grains and the filler metal, resulting in the forming of two different compounds (Cr7C3 and Cr3C2) that allowed for successful joining of the filler metal and diamond grains.

An SEM view of the diamond brazed with the Ni-based filler alloy is shown in Figure 11. An excellent joint has been also successfully accomplished between the steel substrate and the filler metal. Steel substrate and the diamond abrasive grains can thus establish a tough joint thanks to the bridge effect of the "Ni-Cr" filler, an active brazing alloy, to meet needs of heavy load grinding [41].

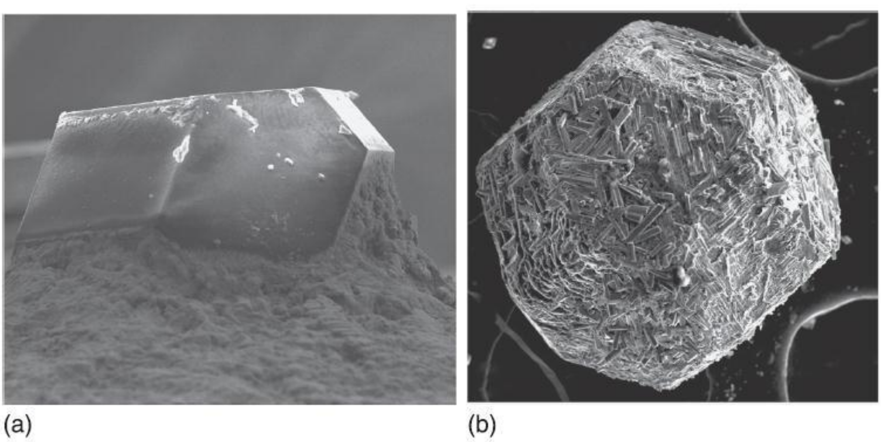

Fig. 11. Carbides forming process .SEM micrograph of diamond brazed with a Ni- based filler alloy (a); carbides formed at the diamond surface (b).

8 Amorphous Ni-based filler alloys

Amorphous alloys possess a distinctively disordered structure, outstanding physical, chemical, and mechanical characteristics, as well assome exceptional qualities that crystalline alloys do not have theseproperties. Amorphous alloy as a filler offers many benefits, including good wetting and fluidity, a small brazing gap, and homogeneous structure and composition of the brazed joining after welding, all of which can greatly enhance the brazed joint's quality.

Amorphous Ni-based filler alloys can provide homogeneous microstructures with minimal macro-segregation and micro-segregation, so after heating these amorphous filler alloys will help to get quickly diffusion composition and fast melting. In comparison to crystalline filler alloys, amorphous filler alloys have a lower initial melting temperature, and under identical brazing temperatures, Amorphous filler alloys must have a greater superheat than crystalline filler alloys [44, 45].

Moreover, the melted amorphous filler alloy also exhibits appropriate, immediate fluidity. from this point, brazing of diamond grits could be perform through low time, in the same time the climbing and wetting between filler alloys and surface of diamond gritswill be completely gotten. As a result, When induction brazing, which hasa typically brief brazing duration, amorphous filler alloy must be utilized.

A research has been performed on the induction brazing of diamond grits, where both crystalline and amorphous Ni-based filler alloys have been used as shown in Figure 12, which represent SEM images of brazing diamond grits during using high frequency induction amorphous filler alloys. It is clear that the amorphous filler alloys have greater wettabilityand climbing characteristics on diamond particles than the crystalline filler alloys.

Its low initial melting temperature can be directly attributed to the filler alloy's excellent wetting and ascent into diamond grits. As long as the climbing and wetting between surface of diamond grits and the filler alloys has been easily carried out, so the filler alloys will be best mechanical holding toward grits of diamond. Therefore, neither diamond particles won't fallen off after brazing nor Under challenging working circumstances, it is tough to fully crack.

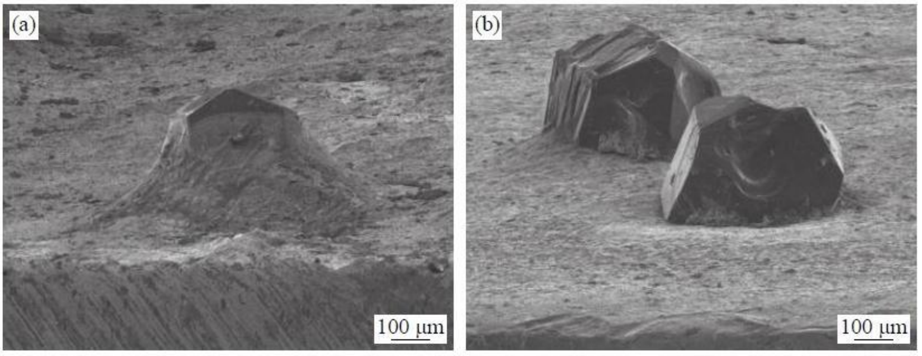

Fig. 12. Shows two types of brazed diamond grits: one with amorphous filler alloy and the other with crystalline filler alloy.

The essence to diamond brazing is that during high temperature brazing, Wetting, diffusion, & their combination can occur closed to interface between diamond surfaces & fillers alloy. These events will strengthen the bonding between the filler alloys with diamond grits. Undoubtedly, the various compositional distributions & melt characteristics of amorphous and crystalline filler alloys are to blame for the differing interface microstructure between diamond and filler alloys. After being eroded in strong acid, the brazed diamond grits are shown in Figure 13. Both brazed diamond grits have Cr3C2 compounds on them [46].

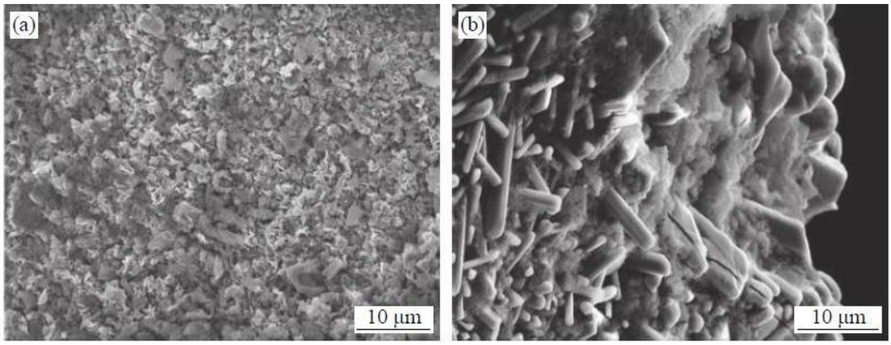

Fig. 13. Shows two types of brazed surfaces that were produced after diamond bars were degraded with strong acid: one was brazed with amorphous filler alloy and the other with crystalline filler alloy.

It is found that the compound on the brazed surface of the diamond grits brazed with amorphous filler alloys are more uniformly distributed and finer than its counterpart. This is because the amorphous filler alloy has a uniform composition. Thus, the fine compound is more crucial than the coarse compound to increase the filler alloy's ability to bonding with diamond grits. [47, 48].

9 Conclusion

Parameters of the diamond/metal interface are studied in relation to chemical-physical characteristics of brazed and diamond tools, when creating a metal matrix for diamond cutting tools, following criteria must be taken into consideration; the affinity with diamond metals that create a carbide coating on diamond surface are typically favored, as they hold the diamond grit without harming it; hardness of the composite material must be proportional to the hardness of the workpiece being cut & must be correlated with diamond wear rate; in order to prevent damage to diamonds during sintering or brazing, the alloy's melting point should be as low as feasible.

We observe that the goal of the investigation into composite filler metals for diamond brazing is to enhance the physical characteristics of the brazed joints, particularly to lessen diamond thermal damage. It can be seen that after brazing, metallurgical reaction results in the formation of carbide between filler metals & diamond abrasives; however, due to incompatibility in thermal expansion coefficient (TEC), this causes a large thermal stress to be created between the diamond and the filler metals during cooling process, which causes crack initiation around the carbide. To enhance the dependability of brazed joints, we advise inventing innovative filler metal to manage carbide thickness at the filler metal to diamond grit interface.

Additionally, brazing techniques should be researched to further optimize the brazing temperature and prevent diamond from becoming graphitized.

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