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Structure design and experimental study on ultrasonic vibration–assisted induction brazing cubic boron nitride abrasive tools

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Abstract
Brazed superabrasive tool has been widely used in machining of difficult-to-cut materials to improve the machining efficiency and quality. However, the severe wear and associated short service life have to be faced for conventional induction brazed (CIB) abrasive tools during machining processes, owing to its weak bonding strength between abrasive grains and metal-bonded phases. In this case, the method of ultrasonic vibration–assisted induction brazing (UVAIB) was proposed to fabricate tools, through introducing ultrasonic vibration into brazing process to improve the abrasive bonding strength. Here, a novel UVAIB device was developed, and the geometric designation parameters were optimized using a finite element simulating method. In addition, the performance of UVAIB device was tested in terms of the impedance and amplitude. Subsequently, the comparative experiment trials were performed with the brazed abrasive tools under the CIB and UVAIB method. Results show that the ultrasonic energy loss of UVAIB device can be reduced, and then, the amplification value and vibration uniformity reach 8 and 92%, respectively. In addition, a large number of pores and macro-cracks inside tool’s metallic matrix for CIB can be observed, whereas the number of pores is reduced by 75%, and only fewer and smaller micro-cracks are found for UVAIB. Furthermore, compared with the grains’ intergranular fracture for CIB, UVAIB exhibits the transgranular fracture mode due to its higher bonding strength after adopting the ultrasonic vibrating method.

Keywords Ultrasonic vibration–assisted induction brazing device · Abrasive tools · Bonding strength · Morphology

1 Introduction
Brazed superabrasive tool has attracted the increasing attentions in the field of aerospace industry, resulting from its extraordinary properties, such as the high bonding strength, large chip storage space, and excellent self-sharpening ability [1–3]. Therefore, the brazed superabrasive tool has broad application in grinding of ductile material [4, 5] and hard-brittle materials [6, 7]. Note that the grinding performance of tools is significantly affected by the mechanical and physical properties between grains and metallic phases. During the conventional brazing process, numerous micropores and micro-cracks inside the connection interface appear, contributing to form the weakened mechanical property of the brazed joint and thus deteriorate the service life of brazed superabrasive tools [8–10]. Therefore, it is urgent to develop a new-type brazing method to eliminate the undesired pores and micro-cracks and improve the grinding performance eventually.

At present, ultrasonic vibration–assisted brazing technology has made beneficial progress in various materials connections at home and abroad. Wu et al. [11] studied the effect of ultrasonic vibration on Al/steel TIG welding-brazing joint. The spheroidization of the Al-Si eutectic, fragmentation of Al3FeSi, and refinement of the aluminum matrix occurred after employing ultrasonic vibrations. In addition, the shear strength of the ultrasonic-treated joint reached 41 MPa, which is higher than that of the raw joint. Note that the effects of cavitation and acoustic
streaming of ultrasonic could promote the chemical metallurgical process of liquid filler alloy during brazing processes [12]. Ultrasonic vibration–assisted brazing could also effectively improve the wettability of materials, especially for various ceramics [13, 14]. Chen et al. [15] prepared ultrasonic vibration–assisted brazed SiC ceramic samples with ZnAlMg alloys and found that the duration time of ultrasonic vibration has a significant impact on the joint’s strength. When the duration time was optimized as 8 s, the strength of joint could reach 148 MPa, satisfying its requirement. Huang et al. [16] fabricated diamond end wheels with the ultrasonic vibration–assisted induction brazing method. They found that the shear strength of joints could be increased by 28.5%, and the fracture failure of joints was greatly reduced. However, there are few reported literature on the preparation of abrasive tools using UVAIB technology during machining the side of workpiece.

On the other hand, ultrasonic vibrating device as the foundational setup to generate ultrasonic vibration has been widely used in various machining processes, such as grinding [17–20], cutting [21–23], milling [24, 25], and forming [26, 27]. Cao et al. [28] designed a novel ultrasonic vibration plate sonotrode, and the measured ultrasonic vibration amplitude and plate vibration uniformity were 7.6 μm and 95%, respectively. In addition, the normal and tangential grinding forces were decreased by 35% and 39%, respectively, and an improved machined surface was obtained. Zhao et al. [29] designed an ultrasonic elliptical vibration–assisted grinding device by means of the integrated non-resonant and conducted the grinding experiment with Nano-ZrO2 ceramics. The grinding mechanism has been changed and the generation of grinding defects has been reduced. Bai et al. [30] put forward an ultrasonic elliptical vibration cutting device to perform the ultra-precision cutting of pure iron. The mirror surface could be achieved with almost no tool wear. Du et al. [31] proposed a piezoelectric ultrasonic milling tool with longitudinal and bending vibration and achieved a reduction of 39.3% cutting forces compared with the conventional milling. However, there is currently insufficient research on the development of UVAIB devices.

In this paper, a novel UVAIB device is developed to fabricate high-performance superabrasive tools and analyzed the influences of ultrasonic acoustic effects on the surface morphology and abrasive bonding strength of brazing joint. Section 2 introduces the experimental setup of UVAIB. Section 3 establishes the frequency equation of the UVAIB device, conducts geometric parameter design and optimization, and tests the performance of the UVAIB device, including impedance and amplitude. Section 4 conducts a comparative investigation to verify the advantages after applying ultrasonic vibrations.

2 Experimental details

2.1 Operation method of the UVAIB device

The UVAIB device includes an induction brazing system, a motion control system, and an ultrasonic vibration system, as shown in Fig. 1. The induction brazing system is composed of an induction brazing machine, an induction coil, and a gas protection device. Here, the skin effect of electric current to heat the local part of the abrasive tool is employed to realize the brazing connection between CBN superabrasive grains and filler alloys. In addition, the entire induction brazing process should be carried out under the condition of Ar gas protection to prevent the filler from oxidizing. In addition, the motion control system consists of a driver, a power supply, a PLC, and a motor, controlling the movement of the sliding table through PLC to adjust the moving direction and speed of the induction coil. Meanwhile, the movement of induction coil during brazing processes is employed to distribute the magnetic induction line uniformly. However, the form of dense in the middle is used to generate more heat, and the sparse at both ends is used to reduce heat. Therefore, the heating of the grinding wheel is uneven, leading to a large temperature gradient during brazing [32, 33]. In order to heat the abrasive tool evenly, it is necessary to control the induction coil to move while heating in order to improve the brazing quality. The ultrasonic vibration system comprises a transducer, a horn, an abrasive tool, an ultrasonic generator, and a supporting structure. Through the action of the transducer and horn, electrical energy is converted into vibration mechanical energy, and then, the vibration is amplified and transmitted to the abrasive tool connected to the horn through threads. At this time, the end of the abrasive tool will obtain the maximum ultrasonic amplitude. Relying on the UVAIB device, the beneficial effects of ultrasonic are used to achieve a high-quality connection between abrasive grains and filler alloy.

2.2 Experimental device and method

The filler alloy used in this study is Cu-Sn-Ti metal powder, the size of CBN abrasive grain is 40/50 mesh, the substrate material of abrasive tool is 316L stainless steel, and the ultrasonic resonance frequency is 30 kHz. The experimental setup is shown in Fig. 2. Before brazing, place the ultrasonic vibration device in the appropriate position of the sliding table, and place the abrasive tool in the center of the induction coil. Subsequently, adjust the coil to an initial brazing position about 10 mm below the part covered with filler. When brazing, first increase the current slowly to 7 A to preheat the grinding wheel for 80 s, which is to accumulate
heat for brazing. Subsequently, control the induction coil to move upward at a uniform speed of 1.5 mm/s, and when it is observed that the filler alloy is completely melted, ultrasonic vibration should be applied immediately. Finally, a single-layer brazed CBN abrasive tool was obtained.

### 2.3 Abrasive grain shear test

The joint strength of the brazed joints was assessed by an abrasive grain shear test. As shown in Fig. 3, the abrasive tool was clamped by a cross vice, a portable microscope was used to assist in tool setting, and the abrasive grains were sheared with a cutting knife clamped by a tensile testing machine whose speed was 0.4 mm/s. A scanning electron microscope (COXEM 30) was used to observe the failure forms of brazed CBN abrasive grains after tests.

### 3 Structure optimization and performance test of the UVAIB device

#### 3.1 Structural parameter design of the UVAIB device

In the process of UVAIB, the horn plays the role of transmitting sound waves and amplifying ultrasonic vibration.
Therefore, the design quality of the horn has an important impact on the performance of the UVAIB device. Due to the limitation of the structural size of the brazing platform, an ultrasonic horn with a resonant frequency of 30 kHz is developed, which can meet the requirements that the abrasive tool vibrate at the natural frequency when brazing. In addition, the horn with this simple shape machining tool as a load can be equivalent to a multi-step transition section stepped horn that is easy to calculate. A stepped horn is shown in Fig. 4a. The frequency equation of the stepped horn is as follows [34]:

\[
\tan(\varphi_1 + \varphi_2) = 0 \tag{1}
\]

\[
\varphi_1 = k_1 l_1 \tag{2}
\]

\[
\varphi_2 = \arctan \left( \frac{Z_{02}}{Z_{01}} \tan(k_2 l_2) \right) \tag{3}
\]

where \( \varphi_1 \) and \( \varphi_2 \) are the shape factors, \( k = \omega / c \), \( \omega \) \( (\omega = 2\pi f) \), \( c = \sqrt{E / \rho} \), \( Z_{0n} (Z_{0n} = \rho c s_n) \), and \( s_n (s_n = \pi D_n^2 / 4) \) are the circular wave number, the circular frequency, the propagation velocity of longitudinal wave in the material, the impedance, and the cross-sectional area of each section, respectively. In addition, \( f \), \( E \), \( \rho \), \( D_n \), and \( l_n \) are the resonant frequency, the elastic modulus, the density of the material, the diameter, and length of the input section and output sections, respectively.

A three-step transition stepped horn is shown in Fig. 4b. According to the long line theory, the stepped horn with multi-step transition section can be regarded as an acoustic transmission line, and the latter section can be regarded as the load impedance of the former section. Consequently, the frequency equation of the three-step transition stepped horn can be obtained by the recursive method as follows [35]:

\[
\tan(k_1 l_1 + \varphi_1) = 0 \tag{4}
\]

\[
\varphi_1 = \arctan \left( \frac{Z_{02}}{Z_{01}} \tan(k_2 \varphi_2 + \varphi_2) \right) \tag{5}
\]
where $D_1$, $D_2$, and $D_3$ and $l_1$, $l_2$, and $l_3$ are the diameter and length of the input, transition, and output sections, respectively. In addition, the circular wave number is equal, that is, $k_1 = k_2 = k_3$, owing to the same material of each horn part. Based on the abovementioned equation, the size of the three-step transition stepped horn can be obtained.

### 3.2 Optimizing designation parameters of the UVAIB device

Figure 5 shows the modeled UVAIB device components (e.g., transducer, horn, and abrasive tool) using 3D analysis software and the associated analyzing results. Here, the modal analysis of UVAIB device is carried out with ANSYS software, and the longitudinal vibration mode is extracted. The material properties are defined in Table 1. By adjusting the length of each section of the horn, a suitable structure for the best brazing quality can be obtained. Considering the energy loss in the process of ultrasonic propagation, it is necessary to make the displacement at the connection between transition section and abrasive tool as small as possible to reduce unnecessary friction loss. As shown in Fig. 5b, the growth rate of amplitude on both sides of the last node is different, and the closer it is to the end face of the transition section, the faster the amplitude increases. Therefore, it is hoped that the position of the node is close to the end face of the transition section. That is, the value of $x$, which is equal to $x_2$ minus $x_1$, should be small. Where $x_1$ is the location of the last node, $x_2$ is the end face position of the transition section.

In addition, the designed ultrasonic vibration device should have a large amplification factor $M_p$ (the ratio of the relative output displacement $\xi_3$ to the relative input displacement $\xi_1$) to study the influence of ultrasonic amplitude on brazing quality, and thus, the amplitude can be adjusted in a large range scope. Furthermore, the part of the abrasive tool covered with filler alloy should vibrate more evenly as much as possible to obtain a higher quality brazed abrasive tool. Meanwhile, the ratio $\delta$ of the relative vibration displacement $\xi_2$ at brazing starting location to the relative vibration displacement $\xi_3$ at the end face of abrasive tool should keep a large value.

| Component               | Material                | Density $\rho$  | Elastic modulus $E$ | Poisson’s ratio $\nu$ |
|-------------------------|-------------------------|-----------------|---------------------|-----------------------|
| Horn/wheel              | 316L                    | 7930 kg/m$^3$   | 200.0 Gpa           | 0.29                  |
| Electrode sheet         | Beryllium bronze        | 8250 kg/m$^3$   | 122.6 Gpa           | 0.35                  |
| Front/rear cover plate  | 6061Al                  | 2750 kg/m$^3$   | 72.0 Gpa            | 0.33                  |
| Piezoelectric ceramic   | Piezoelectric ceramics  | 7600 kg/m$^3$   | 68.0 Gpa            | 0.30                  |
In practice, the size of $D_1$ is determined by the transducer end face, and the size of $D_3$ and $l_3$ is determined by the abrasive tool. Therefore, considering the influence of transition section diameter on the performance of horn, the different $D_2$ are taken for calculation, and the corresponding values of $l_1$ and $l_2$ can be obtained. According to the calculation results, the relationship between the length of $l_2$ and $l_1$ is shown in Fig. 6a. When the length of $l_2$ increases from 20 to 90 mm, the length of $l_1$ shows a downward trend. In addition, the larger the value of $D_2$, the faster the length of $l_1$ will drop in the range of 20–60 mm. However, when the length of $l_2$ is in the range of 60–90 mm, the length of $l_1$ tends to be the same for different $D_2$.

After modeling with the above values and carrying out the modal analysis, the effect of length of $l_2$ on the relative distance of node is obtained (Fig. 6b). When the length of $l_2$ increases from 20 to 40 mm, the relative distance of node keeps decreasing. When the length of $l_2$ is in the range of 40 to 60 mm, the relative distance of the node tends to be stable, which fluctuates only in a small range. Once the length of $l_2$ reaches 60 mm, the relative distance of the node generally becomes an upward trend. Especially from the overall trend, when the value of $D_2$ increases, the relative distance of the node will also increase. Therefore, in order to obtain a small relative distance of the node, the length of $l_2$ should be in the range of 40 mm to 60 mm.

![Fig. 6](image_url)
As a result, the amplification factor is studied under the above restrictions. As shown in Fig. 6c, when the length of $l_2$ increases from 40 to 60 mm, the amplification factor for different $D_2$ shows a straight upward trend. In addition, as the value of $D_2$ increases, the corresponding amplification factor also increases. Therefore, for the consideration of obtaining a large amplification factor, the length of $l_2$ is decided to be 60 mm. Besides, combined with Fig. 5b, in order to obtain a small relative distance of the node and a large amplification factor simultaneously, the value of $D_2$ should be 19 mm.

It is known that when the length of $l_2$ is 60 mm, the corresponding length of $l_1$ is about 80 mm. Thus, in order to obtain a higher vibration uniformity, the influence of length of $l_1$ on the vibration uniformity is studied, which is in the range of 76 mm to 84 mm. As shown in Fig. 6d, when the length of $l_1$ increases from 76 to 84 mm, the vibration uniformity first decreases and then increases. When the length of $l_1$ is 80 mm, the vibration uniformity of the UVAIB device is 92%, which is the highest value. Subsequently, the value of vibration uniformity shows a downward trend. Therefore, the length of $l_1$ is determined to be 80 mm.

In summary, the size of the horn is determined as $D_2 = 19$ mm, $l_1 = 80$ mm, and $l_2 = 60$ mm. The simulation results indicate that the resonant frequency of the ultrasonic vibration device is 30171 Hz, and after setting the flange, the resonant frequency becomes 30,243 Hz, as shown in Fig. 7. At this time, the ultrasonic energy loss can be reduced, the amplification factor can reach 8, and the vibration uniformity of abrasive tools can reach 92%.

### 3.3 Performance test on the UVAIB device

#### 3.3.1 Impedance analysis test

The horn is manufactured with the optimized size and assembled with transducer and abrasive tool to form an ultrasonic vibration device. The impedance characteristics are analyzed by the PV502A impedance analyzer, and the analysis results are shown in Fig. 8. There is no parasitic circle in the admittance circle diagram, and the impedance-frequency curve is relatively smooth, which indicates that the vibration near the resonance point is ideal. In addition, the dynamic resistance is 38.76 Ω, which shows that the ultrasonic vibration device has high energy utilization during working. The mechanical quality factor is reasonable, which indicates that the conversion efficiency of electric energy and sound energy is high.

From the overall results, there is a difference between the actual value ($f = 30653$ Hz) and the theoretical value ($f = 30243$ Hz) of the resonant frequency, because the material characteristic value is not exactly the same as the defined value of modal analysis. In addition, the horn and the abrasive tool are connected through threads, so the gap generated...
in the assembly process also causes errors. In short, the structure of the horn is reasonable, and the ultrasonic vibration device has good ultrasonic performance.

3.3.2 Amplitude test

Ultrasonic amplitude is one of the key factors affecting the quality of UVAIB. In this text, a laser doppler vibrometer (LV-S01, SOPTOP) was used to measure the ultrasonic amplitude. Five points with the same interval on the end face of abrasive tool are measured for 3 times, and the average value was taken as the amplitude of the vibration device, which is measured to be 5 μm, as shown in Fig. 9. The peak value of the waveform corresponds to the ultrasonic amplitude, and it is found that the longitudinal vibration curve is approximately sinusoidal, which indicates that the ultrasonic vibration device has good ultrasonic performance.

4 Effect of ultrasonic acoustic effect on brazed CBN joints

4.1 Surface morphology of the brazed CBN joints

For CIB, the surface of filler alloy is uneven and contains a large number of pores and small pits, as shown in Fig. 10a, b. However, the UVAIB filler alloy is spread more evenly, and there are a few pores and almost no pits, as shown in Fig. 10c, d. In addition, the number of pores was counted by image processing software, as shown in Fig. 11. It is found that the pore diameter of two methods is both concentrated in the range of 3–9 μm. Meanwhile, compared with CIB, the number of pores of UVAIB decreases by 75% in the area of 1400 μm × 1000 μm, and the pore diameter is smaller. Figure 12 vividly illustrates the formation process of pores for CIB. In this study, the abrasive grains are adhered to the substrate through the adhesive and then paved with a layer of filler alloy evenly. Therefore, when the abrasive tool is heated, the adhesive will volatilize and produce a large amount of gas, which needs to go a certain

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Fig. 9 Amplitude test device and measured results

Fig. 10 Surface morphology of the filler alloy: a, b CIB; c, d UVAIB
distance in the liquid filler alloy to separate. However, due to the fast heating speed and relatively short heating time in the induction heating process, the volatilized gas does not have enough time to discharge. In addition, the cooling rate after brazing is also fast, so a considerable part of the gas fails to separate from the filler alloy before solidification, which results in a fact that a large number of pores will be formed inside and on the surface of the filler alloy.

Besides, the filler alloy is a blend of different metal powders. Although it is dispersed by physical vibration before distributing on the substrate of abrasive tool, some filler alloy is still agglomerated together, which will make the filler layer loose and empty when brazing. Meanwhile, the filler alloy is manually sprayed on the surface of abrasive tool layer by layer, which is impossible to ensure the uniformity of filler layer thickness and will lead to hollow structures of filler layer. Therefore, these factors will inevitably lead to pits and roughness on the filler surface after brazing.

However, the surface morphology of UVAIB joints remains in good condition. The obvious difference can be attributed to the ultrasonic oscillatory motion, acoustic streaming effect, and cavitation effect. As shown in Figs. 12 and 13, the mixing and flow of filler alloy are enhanced under the action of ultrasonic oscillation, and the filler alloy tends to be uniform and flat. In addition, ultrasonic oscillation motion is also conducive to gas escape.

At the same time, the acoustic streaming effect also has a beneficial effect on the brazing process. When ultrasonic
propagates in the liquid filler alloy, due to the absorption and attenuation of sound wave, it will form a sound pressure gradient from the sound source to its propagation direction, which will promote the flow of liquid filler. Furthermore, when the amplitude of ultrasonic vibration increases to a certain value, this non-periodic movement will produce a fluid jet phenomenon in the filler, and its flow speed is greater than that generated by the thermal convection inside the liquid filler. Therefore, the acoustic streaming effect can speed up the flow of liquid filler, which not only makes the pores reduce but also makes the filler layer flat, as shown in Figs. 12 and 13.

In addition, when ultrasonic vibration acts in the liquid filler alloy, the tiny bubbles in the filler will be stretched and become cavitation bubbles. Subsequently, these cavitation bubbles will collapse under pressure. During this process, an instantaneous high-temperature and high-pressure environment was produced in local areas, which is shown as a strong shock different from the macro vibration. Moreover, the high temperature, high pressure, and micro jet caused by ultrasonic cavitation will produce many local reactions in the liquid filler, which can promote the chemical metallurgical reaction of brazing. At the same time, the collapse of the cavitation bubble can realize the stirring of the liquid filler alloy. Therefore, the gas in it can escape more easily.

4.2 Physical property of brazed CBN joints

4.2.1 Cracks on brazed CBN joints

The cracks of CIB and UVAIB joints are compared in Fig. 14. For CIB, it can be found that long and wide macro-cracks distribute on the bond zone (Fig. 14a, b). However, only fewer and smaller micro-cracks are found on the joints of UVAIB (Fig. 14c, d). It is known that the brittle CBN abrasive grains, plastic Cu-Sn-Ti filler alloy, and stainless steel substrate of abrasive tool have a difference in thermal expansion coefficient, which will cause the mismatch of connecting components. Therefore, the brazed CBN abrasive grains will show thermal damage after brazing, which may cause cracks on the grains. Moreover, due to uneven temperature changes, thermal residual stress will be generated during brazing. These factors lead to the existence of many macro-cracks on the CIB joints, which will inevitably reduce the strength and wear resistance of the grains. However, for UVAIB, since the ultrasonic oscillation motion and the acoustic streaming effect can accelerate the heat transfer of molten filler alloy and make the brazing temperature more uniform, the degree of thermal damage and thermal residual stress can be alleviated. Therefore, there are fewer and smaller micro-cracks on the brazed joints.

4.2.2 Fracture forms of brazed CBN abrasive grains

After the abrasive grain shear test, the fracture forms of abrasive grains are compared in Fig. 15. It is found that the abrasive grains of CIB fail in the form of intergranular fracture. Many pores are found at the interface between abrasive grains and filler alloy, as shown in Fig. 15a. However, the abrasive grains of UVAIB fail in the form of transgranular fracture, as shown in Fig. 15b, and it is found that the bonding interface remains in good condition. The evolution process of abrasive grains failure is shown in Fig. 16. For CIB, when
the abrasive grains are subjected to a shear force, the cracks will first appear at the location of pores in the filler alloy. This is because these pores are places of stress concentration, which will easily become crack initiation. When the shear force increases, these micro-cracks will grow into macro-cracks, and filler alloy will lose control of abrasive grains. Finally, the abrasive grains fail in the form of intergranular fracture. Therefore, the existence of pores will weaken the holding force of filler alloy on abrasive grains.

For UVAIB, on the one hand, there are a few pores on joints. Therefore, the holding force will be basically unaffected. When the shear force increases, the micro-cracks will first appear on the grains and then expand into macro-cracks. Finally, the abrasive grains fail in the form of transgranular fracture, as shown in Fig. 16, which indicates that the holding force of filler alloy on abrasive grains exceeds the fracture strength of abrasive grains. On the other hand, the cavitation effect will occur at the capillary gap in the liquid filler alloy. The generation, growth, and collapse of these cavitation bubbles will produce large local pressure and strong ultrasonic impact, which can break the precipitated phase and make large grains into small pieces. Meanwhile, these small pieces become new nucleation centers that will promote the growth of new grains. Therefore, ultrasonic
vibration refines the grains, which can optimize the brazing structure and improve the holding force of filler alloy on CBN abrasive grains.

5 Conclusion

In this paper, through the combination of theory and simulation, an UVAIB device is developed for the manufacture of brazed CBN abrasive tool, and the advantages of ultrasonic vibration in improving brazing quality have been verified by UVAIB experiment. The following conclusions are drawn:

1. An UVAIB device is developed, and the longitudinal ultrasonic vibration with an amplitude of 5 μm is achieved on the end of abrasive tool. The amplification factor and vibration uniformity of the abrasive tool are the key factors in the design of the ultrasonic vibration device. In this work, the ultrasonic energy loss of the UVAIB device could be reduced, and then, the amplification factor value and vibration uniformity could reach 8 and 92%, respectively.

2. For CIB, the surface of the filler alloy is uneven, and there are a large number of pores and macro-cracks on the joints. However, the UVAIB filler alloy is spread more evenly. The internal pores inside the metallic matrix were reduced by 75%, and only fewer and smaller micro-cracks could be found.

3. The abrasive grains of CIB failed in the form of intergranular fracture, while those of UVAIB failed in the form of transgranular fracture, which could be attributed to the stronger bonding strength of UVAIB joints compared with CIB. These beneficial effects are due to the work of ultrasonic oscillation motion, acoustic streaming effect, and cavitation effect.

4. In the further investigation, the interface reaction mechanism and grinding application should be focused after revealing the microstructure and mechanical properties of brazed superabrasive tools for UVAIB. In addition, a large size ultrasonic brazing setup can be developed to satisfy a higher grinding speed requirement for brazed superabrasive tools.

Author contribution Kaida Cai: experimentation, data curation, and writing the original draft. Biao Zhao: data collection and manuscript revision. Bangfu Wu: experimentation and methodology. Wenfeng Ding: supervision, conceptualization, and methodology.

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Availability of data and material All data generated or analyzed during this study are included in the present article.

Declarations

Ethics approval and consent to participate The article follows the guidelines of the Committee on Publication Ethics (COPE) and involves no studies on human or animal subjects.

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Competing interests The authors declare no competing interests.

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