Ceramics International xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Vacuum brazing of cubic boron nitride to medium carbon steel with Zr added passive and Ti activated eutectic Ag-Cu alloys

D. Raghava Simhan, Amitava Ghosh*

Indian Institute of Technology Madras, Chennai 600036, India

ARTICLE INFO

Keywords:
CBN brazing
Diffusion
Zr segregation
Interfaces
Electron microscopy
Wear resistance

ABSTRACT

Active element like Ti is usually added to Ag-Cu passive alloy to braze cubic boron nitride (cBN) ceramic particles with steel substrate under high vacuum. Current work focusses on another group-IV element Zr, having more negative Gibbs free energy than Ti, concerning its reaction capability with cBN. In the present study, its effectiveness as an additive to the 72Ag28Cu alloy in brazing of cBN has been investigated. Zr is added to both passive and Ti-activated Ag-Cu alloys. Interestingly, the addition of 2 wt% Zr to the composition of eutectic alloy fails to braze cBN, unlike the addition of 2 wt% Ti. The underlying science is critically investigated. A new formulation of the alloy with the composition of (72Ag28Cu)-4Zr-4Ti alloy is found to be a beneficial alternative. Wetting of this new alloy on cBN is appreciable and simultaneously an additional benefit of 50% increase in wear resistance is achieved, compared to the (72Ag28Cu)-2Ti alloy. A significantly hard new intermetallic phase, $AgCu_4Zr$ is detected in the microstructure which contributes to the enhancement of wear resistance of the new alloy. The joint strength thus achieved in brazing cBN with medium carbon steel using (72Ag28Cu)-2Ti and (72Ag28Cu)-4Zr-4Ti alloys is also compared but found to be compromised in case of the later. The results are analyzed in the light of microstructure, alloy-cBN interfacial chemistry and interfacial fracture under load.

1. Introduction

Cubic boron nitride (cBN) is a ceramic, which in its particle form is recognized as a superabrasive grit by grinding industries. It possesses very high hardness and excellent thermo-chemical stability. cBN grits are used to produce superabrasive grinding wheels for machining a wide range of high strength steels, nickel based super alloys and other hard materials [1,2]. Grinding wheels which are of single layer configuration, essentially require cBN grits to be joined to a steel substrate. Active brazing technology inherits certain advantageous attributes over commonly adopted electroplated technology in this regard. It is possible to realize larger grit protrusion, more inter grit space for chip accommodation due to the characteristic nature of metallurgical bonding of cBNs in case of active brazing process [3,4]. However, brazing of cBN to a metal substrate is quite challenging since no passive metallic alloy can wet cBN due to the covalent nature of its chemical bonding [5,6]. Therefore, addition of an active element to the alloy becomes inevitable and the element being added should possess greater chemical affinity towards cBN to break the B-N chemical bond. This leads to the formation of intermetallic compounds between the active element and cBN at the cBN-alloy interface, which are in turn wet by the filler alloy [7] establishing a strong braze-joint.

Several commercial filler alloys such as Ni based, Cu based, Au based and Ag based alloys are available for brazing of ceramics to metals. Ni-Cr alloys, which are often preferred for the brazing of diamond [8], don't wet cBN [9,10] owing to the non-reactivity of its constitutive element Cr towards cBN. Therefore, Cu and Ag based active alloys remain as the widely sought out filler materials for the brazing of cBN. Ag based alloys are usually favoured because of its excellent ductility and lower liquidus temperature [11]. Chattopadhyay et al. [2], Ghosh et al. [12,13] and Ding et al. [14] have carried out extensive research on the brazing of cBN using eutectic Ag-Cu active alloy. These Ag based alloys contain titanium (Ti) as the sole active element, which reacts with the cBN forming intermetallic compounds such as TiN and TiB_2 [15–17]. Moreover, the Cu in the eutectic Ag-Cu alloy also forms solid solution with the added Ti forming intermetallic compounds such as Cu_4Ti, Cu_3Ti_2 [18]. These intermetallic compounds are further wet by the Ag based alloy [19–21], thus resulting in the continuity of the solidified melt and subsequently securing the grits firmly in the bonding matrix. The microstructural development of the alloy during the brazing operation, effect of brazing time and temperature on the cBN-filler alloy interface and the reactions in the filler alloy-cBN and the substrate-filler alloy interfaces have been previously investigated in depth by researchers. The thermodynamics of the reactions and the

* Corresponding author.
E-mail addresses: d.raghavasimhan@gmail.com (D.R. Simhan), amitava_g@iitm.ac.in (A. Ghosh).

https://doi.org/10.1016/j.ceramint.2017.12.079
Received 20 October 2017; Received in revised form 11 December 2017; Accepted 11 December 2017

compound formations have also been given due importance in analyses of the reported literature [22]. However, active Ag based alloy, though it exhibits excellent wettability and appreciable coverage of the grits, is reported to be quite soft and thus poor in wear resistance [11,23]. Hence, the alloy wears out quickly leading to the premature failure of the grits. Additives like TiC, TiB_2 [24,25] ceramic particles are added to the filler alloys to improve the performance of this alloy. Overall, a copious amount of published research is available in the area of cBN brazing with Ti added active Ag based alloy.

Interestingly, the notion of an element functioning as the activating element is pertaining not only to titanium (Ti) but to all group IV elements (to which Ti belongs) in the periodic table, such as Zr and Hf. Of these, Zr is apparently a more suitable alternative as it has similar electronic configuration to that of Ti with its unsaturated outer shell d-orbitals ($3d^2$ and $4d^2$ for Ti and Zr respectively). Also, the larger negative Gibbs free energy of formation of borides and nitrides of Zirconium (Zr) at the brazing temperature conveniently suggests that they should develop a strong bond with the cBN which possibly improves the strength of the brazed joint. Only a few literature claimed that the Zirconium [26,27] can be a plausible alternative to Ti as an active element, but as such no research data is available which has dealt with the application of Zr in the brazing of cBN.

Therefore, under the current work, an in-depth fundamental study to explore the suitability and performance of Zr in the Ag-Cu alloy in brazing cBN to a medium carbon steel substrate is prioritized. Aiming at utilizing Zr effectively, Zr is mixed with both passive and Ti-activated alloy. The performance of the typical alloy formulations with or without Ti in the brazing of cBN is studied comprehensively in terms of wettability of the alloy on cBN, microstructural characterization, X-ray Diffraction analysis, individual reactivity of Ti and Zr with cBN and formation of interfacial reaction compounds along with the evaluation of strength of brazed joint. The results are critically analyzed and the suitability of Zr as the active element in the brazing of cBN is addressed elaborately.

2. Materials & methods

2.1. Preparation of filler alloy and brazing of cBN

Eutectic Silver based alloy (72Ag28Cu) is procured from Morgan Advanced Ceramics, USA and mono crystalline cBN of size B427 is purchased from Sandvik hyperion, USA for the brazing operation. Additive elements, Ti and Zr of very high purity (of the range of 99.99%) are procured from Alfa Aesar, USA. These active elements are thoroughly mixed with the filler alloy. The morphology of the mixed alloy is shown in the Fig. 1. cBNs are brazed to a metal substrate at 850 °C (well above the alloy's liquidus temperature) and is held at that temperature for 5 min to facilitate the occurrence of interfacial reactions. A sophisticated vacuum brazing furnace is built up for this purpose and is coupled with a turbo molecular pump that can maintain a vacuum of 10^{-7} mbar inside the heating zone during brazing. Temperature in the heating zone is controlled with the help of a PID controller linked with two precisely calibrated Pt-Rh/Pt thermocouples. AISI 1045 medium carbon steel is chosen as the substrate for this study and the samples are ultrasonically cleaned for a period of 10 min before being loaded on to the furnace. After the brazing operation is completed, the brazed samples are subjected to microscopical investigation under a high resolution INSPECT F50 Field Emission Scanning Electron Microscope (make: FEI) equipped with EDS (Energy Dispersive Spectroscopy) to examine the different phases obtained. The X-Ray Diffraction (XRD) analysis is carried out in a BRUKER D8 make XRD machine at a scan speed of 1 step/sec to identify the intermetallic phases formed at the cBN interface, after successfully reducing the sample to its near cBN interface via electrolytic etching.

2.2. Evaluation of microhardness and abrasion resistance of alloys

For finding the microhardness of the alloys, the respective alloys are melted on a mild steel substrate and are polished to a mirror finish. The microhardness of the samples is tested using a Micro Vickers Hardness machine (Future tech F70, Japan) with an applied load of 25 gf and 500 gf for a dwell period of 10 s as per ASTM standard E384-11. The small load of 25 gf is applied to find the hardness of the smaller size intermetallic phases that form in the alloy and the higher load 500 gf is for the bulk microhardness of the alloy. An average of five readings is taken in all the cases.

The wear resistance of the alloys is tested using a Pin on Disc Tribometer TR-20-M52 of DUCOM make as shown in Fig. 2. The test is carried out as per ASTM standard G99-05. The sample pin is prepared by melting the filler alloy on a 6 mm diameter medium carbon steel pin. The pin is then brought into contact with a SiC emery sheet fixed on a disc, rotating at 2000 RPM under an external normal load of 0.4 Kgf for a period of 2 min. The volume of the material lost as a result of the wear of the material is calculated with the help of difference in weights of the pin before and after the test and also by calculating the density of the alloy.

2.3. Evaluation of the mechanical strength of the brazed joint

An indigenously built test rig is used to evaluate the joint strength of brazed cBN. The setup is built with computer numerically controlled (CNC) single axis linear movement coupled with a rotary motion, which

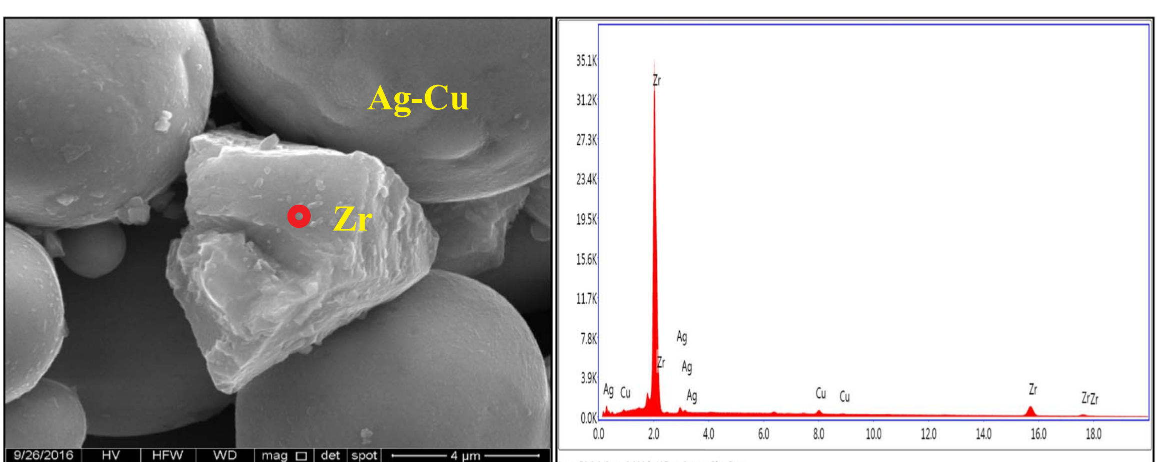

Fig. 1. Morphology of (72Ag28Cu)-2Zr alloy.