BIO Web of Conferences **129**, 23004 (2024) https://doi.org/10.1051/bioconf/202412923004
EMC 2024

Exploring novel joining technique of Gas Actuated Bonding by utilizing In-situ Environmental-TEM

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Background

The reliability of a critical industrial component is decided by the durability of the weakest joint or spot. For applications involving high-temperature operational conditions especially coupled with corrosive environments like fuel cell interconnections, molten metal baths, etc., the joints are the most vulnerable regions for catastrophic failure due to localized material degradation by selective corrosion leading to compromised mechanical behavior. The existing joining techniques lead to a continuous metallic phase with modified microstructural characteristics at the bridging junctures or employ a joining alloy that integrates two parent materials. These bridging phases are proving to be the weakest points of the components because they are prone to corrosion compared to parent materials. This is effectuated by the microstructural transformation as well as local compositional fluctuation incorporated in the bridging phases as a consequence of the joining techniques and procedure currently in use. On the other hand, the semiconductor industry utilizes emerging brazing technologies built on well-established Chemical Vapor Transfer (CVT) technologies (e.g., CVD, MOVPE, PVD). Even though both oxide removal and metal migration into the gap are crucial in metal bonding, there is only one published concept for delivery of non-metallic MPD [1], and a few studies of utilizing active gases for oxide removal.

Methods

The methodology of GAB requires the joints to be made from the bulk material itself by utilizing both gaseous oxide removers (OXR) and gas phase melting point depressants (MPD). In transient liquid phase (TLP) diffusion bonding, a method that lies between brazing and diffusion bonding, diffusion is sped up by a metal MPD interlayer. The preparation of superalloys or the brazing of Al-alloys has been conducted by the oxide removing technology which is contemporarily in practice. This process resulted in the best possible corrosion resistance and strength because both the joint and the bulk have obtained a similar surface oxide and microstructure. Furthermore, by introducing melting point depressing gases on metal surfaces, GAB induces a transient liquid phase similar to chemical vapor transport (CVT) technology. The two critical rate-determining steps in GAB are the removal of the pre-existing surface oxides of the nanoparticles and metal migration into the gap corresponding to the effect of temperature of exposure and partial pressure of the MPD precursor gas.

Results

GAB of pure Cu has been studied in-situ Environmental Transmission Electron Microscope (E-TEM) from a nanometer-sized AgCu particle. Temperature was held constant at 520°C, where the particle is identified as solid. After gaseous AsH3 is allowed to flow into the chamber, the particle is observed to alloy with As and is then identified as liquid (without any temperature change). Similar trials are attempted on 316L steel nanoparticles in experiments conducted utilizing a similar setup of in-situ E-TEM wherein GAB is obtained by melting point reduction using phosphine (AsH3). Therefore, we have built upon the well-established Chemical Vapor Transport (CVT) technology to induce a transient liquid phase that could form joints with greatly enhanced mechanical and anti-corrosion properties. This leads to a novel metal joining technology called Gas Actuated Bonding (GAB) wherein melting point depressing (MPD) elements are transported as MPD-precursor gas to the joining zones. This takes place during processing to initiate surface reactions that create a liquid transition phase. This will lead to a profound improvement in the quality and consistency of the bridging phase in terms of microstructural consistency, thermal stability, along with enhanced mechanical properties.

Conclusion

Miniature components can be effectively assembled utilizing GAB by circumventing the need for obstructive fillers through the use of MPD-precursor gases that particularly actuate the outermost surfaces. Thus, heat-affected zones and deformation are subsequently prevented. This further validates GAB as a highly suitable manufacturing technology for such small and complex components. Hence, we can observe a drastic improvement in performance as the joints and bulk will have homogeneous surface oxides and homogeneous microstructure. The GAB mechanism is thus thoroughly investigated and understood by in-situ E-TEM experiments at various partial pressures of the MPD gases and the temperature of in-situ heating.

Graphic description

Preliminary results from GAB of AgCu. a) Schematic illustration. b) Elemental mapping in E-TEM. A nanometer-sized particle of AgCu is observed to be solid at 520°C in a vacuum. When AsH3 is flowed into the chamber the particle alloys with As and melts. c) Isothermal Section of the Ag-As-Cu Ternary Phase Diagram at 500°C. The red line indicates the compositional change of the particle after introducing AsH3.

Graphic:

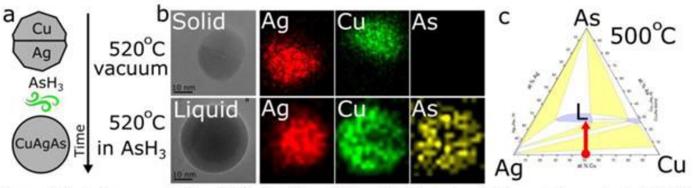

Figure 3. Preliminary results from GAB of AgCu. a) Schematic illustration. b) Elemental mapping in E-TEM. A nanometre sized particle of AgCu is seen to be solid at 520°C in vacuum. When AsH_3 flows into the chamber the particle alloys with As and melts. b) Isothermal section of the Ag-As-Cu ternary phase diagram at 500°C. The red line indicates the compositional change of the particle after introducing AsH_3.

Keywords:

Insitu Environmental-TEM, Gas-actuated bonding, Deoxidation

Reference:

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