Technological Advanced Techniques for Joining Ceramics-Metals/Alloys

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Abstract

Ceramics and metals are two of the oldest established classes of technologically useful materials. While metals dominate engineering applications, ceramics have some attractive properties compared to metals, which make them useful for specific applications. The properties of individual ceramics and metals can vary widely; however, the characteristics of most materials in the two classes differ significantly. Joining of Ceramics with Metals/Alloys is difficult because of the difficulty of mismatching of Coefficient of Thermal Expansion of materials formed in weld pool with components to be joined. Difficulties arise if ceramics sublime rather than melt or the metal undergoes phase changes on cooling. Joints between a metal and ceramic are becoming increasingly important in the manufacturing of a wide variety of technological product. But joining ceramics to metallic materials often remains an unresolved or unsatisfactorily resolved problem. Technological advances are extending the applications for bonded Ceramic-Metal/Alloys components and demanding more rigorous performance characteristics..Successful application of ceramics in many devices and structures requires some type of ceramic metal joining. Ceramic-metal seals are used extensively in a wide variety of applications. Examples include vacuum tubes, high voltage feedthroughs, transistor packages, sapphire-metal windows, rocket ignitor bodies and many others. Newer joining applications include engine components, such as the Si_3N_4 turbocharger rotor joined to a metal shaft now being produced commercially, multilayer electronic devices that comprise both ceramics and electrodes, electroding and metallizing of hybrid microcircuit substrates, and ceramic-metal composites. All applications require a high-strength metal-ceramic bond. Many new techniques have been developed for successful joining of ceramics to metals; Metal-ceramic joining has slowly but steadily become an important manufacturing step. New joining methods and newer approaches to conventional methods have been developed aiming at joints characterized by improved reliability, and interfaces capable of withstanding high-temperature resistance with minimum residual stresses. Some of the Technological advanced Techniques for joining Ceramics to metals are Ultrasonic Joining, Transient Liquid Phase Bonding, Microwave Joining Infiltration Processes, Brazing.

Keywords: Coefficient of Thermal Expansion, Ceramic-metal joining, Brazing, Technological advanced Techniques

1. INTRODUCTION

Joining of Ceramics with Metals is difficult because of the difficulty of mismatching of CTE of materials formed in weld pool with components to be joined. Difficulties arise if ceramics sublime rather than melt or the metal undergoes phase changes on cooling. Many new techniques have been developed for successful joining of ceramics to metals such as Ultrasonic Joining, Transient Liquid Phase Bonding, Microwave Joining Infiltration Processes, Brazing, few of which are discussed below:

1.1 Ultrasonic Joining

Ultrasonic joining, which is used extensively in the plastics industry, has been used for ceramic/metal combinations such as alumina/aluminum, alumina/stainless steel, zirconia/steel and glass ceramic/copper. Typical applications include batteries, thread guides, textile cutting equipment and heavy duty electrical fuses. The advantages of the process are the very fast joining times (less than one second), the fact that surface preparation is not critical (contrary to almost every other ceramic joining process) and the lack of melting and intermetallic formation. However, to join hard metals such as steel, soft, deformable interlayer's are needed. One limitation of ultrasonic joining of ceramics is that only films or thin sheets of metal can be joined to a ceramic.

1.2 The Process

Ultrasonic joining requires a transducer assembly operating at about 20 kHz (the source of the ultrasound) coupled to a sonotrode. The sonotrode tip is placed in contact, usually under a clamping load of 1-10Nmm^{-2}, with the work piece, **Chart 1**. The heat generated is localized at the interface, creating a temperature of up to 600°C when using aluminum interlayer's.

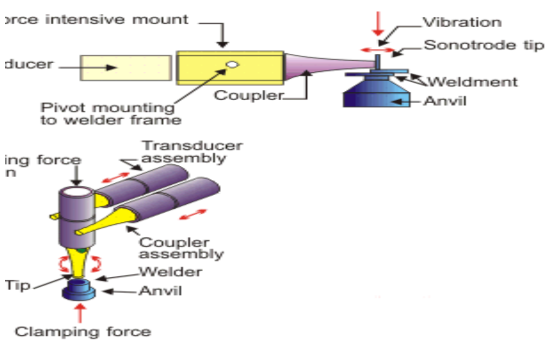

Chart 1. An ultrasonic welding set up.

The bonding mechanism relies on the vibratory shear stress of the metal exceeding its elastic limit, coupled with the breakdown of surface oxide films exposing atomically clean metal. The clamping force exerts plastic deformation on the metal, which increases the interfacial contact between the metal and ceramic. Mechanical keying then occurs across the interface and the joint is formed, perhaps along with some chemical interactions.

Applications

In future, ultrasonic joining could be applied to gas-tight container seals (lamps), optical components and joining metallic membranes onto ceramic bodies.

2. Transient Liquid Phase Bonding

Another technique, transient liquid phase bonding (TLPB), has the ability to produce a bond at a lower temperature than that at which it will be ultimately used. The technology is currently being adapted for a number of ceramics using 'interlayer's' based either on glasses (such as oxynitrides for joining SiAION) or pure metals or alloys (such as Ge and Ge-Si for joining SiC and SiC/SiC composites).

Bonding in the SiAlON system is shown in **Chart 2**. A mixture of silicon nitride, yttria, silica and alumina are applied by spray coating to one surface of the joint. As the samples are heated to 1600°C, a load of $2MNm^{-2}$ is applied. Joint formation occurs at this temperature over a period of 10-80 minutes. At about 1400°C, the oxide components react to form a Y-Si-Al-O liquid phase. This leads to densification and sintering. The silicon nitride then dissolves into the liquid, boosting both Si and N contents and altering the composition to Y-Si-Al-O-N. At the same time, (ß-SiAlON grains grow and form an interlocking network across the joint, forming an in-situ reinforcement phase. A secondary process is the diffusion of the adhesive mixture into the surrounding adherent material. Within this diffusion zone the composition and properties of the ceramic gradually change.

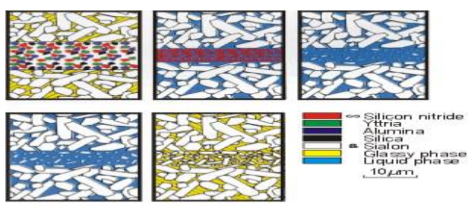

Chart 2. The transient liquid phase bonding process.

The weakness of the TLPB method is that a favorable reaction between the interlayer and the substrates is required. For silicon nitrides, the glassy interlayer must redistribute itself and penetrate the adjoining microstructure.

3. Infiltration Processes

High strength, high temperature materials for operation in excess of 1000°C, such as SiC-based composites, are needed for structural applications such as heat exchangers and gas turbine components. This is because traditional stainless steels and superalloys have reached their operational limits. Industry therefore wants to develop a robust joining process suitable for both

SiC monolithic and composite materials. Polymers that react with and infiltrate into the bulk material offer a potential solution.

In these so-called infiltration processes, a mixture of polymer precursor (a source of carbon), aluminum, boron and silicon is applied to the joint surfaces (in a tape, paste or slurry) and then heated, generally to 1200°C, in an inert atmosphere and/or air using a propane torch or furnace. The joint forms through pyrolysis of the polymer precursor material, which subsequently reacts with the silicon in the presence of aluminum and boron sintering aids to form in-situ, high density SiC. Strengths range from about 95 MNm^{-2} for air-joined samples down to 40 MNm^{-2} for argon atmosphere samples. The fact that the joint can be produced using a simple gas torch could have a major impact on the repair or on-site production of ceramic/ceramic joints. So far, various grades of SiC, SiC/SiC and C/SiC composites have been joined using this technique.

4. Microwave Joining

Microwaves provide another technique for joining ceramics together. Microwave energy is already being applied to the drying/firing of refractories and whiteware. Now it is being considered as an energy source for joining ceramics such as alumina, zirconia, mullite, silicon nitride and silicon carbide. The direct coupling of the microwave with the ceramic results in volumetric heating, and so there is great potential for heating large sections uniformly. Control of the location of the maximum electric and magnetic fields also enables precise, selective heating.
Conventional diffusion bonding techniques use radiant heating methods and so the time to reach temperature and the time at bonding temperature can be as long as 8 hours. This is particularly the case for materials such as alumina, which are diffusion bonded at temperatures approaching 1600°C. Using a microwave heat source, bonding times can be reduced by an order of magnitude.
Very high purity alumina is difficult to heat, owing to low inherent dielectric properties making joining difficult. Impure, 85% alumina on the other hand is joined easily. The use of interlayers, including sealing glasses, and alumina gels has both been investigated for producing joints with high purity alumina. Alumina gels offer the advantage that, at the joining temperature, the gel transforms into colloidal α-alumina which subsequently sinters to provide an homogeneous interface. Joints between 85% alumina show bond strengths equivalent to that of the parent material. Joint formation has been studied and a number of possible mechanisms have been identified, depending on the material. For impure alumina, the glassy grain boundary phase softens and assists in the bonding process, while for zirconia, a solid state process has been identified.

5. Brazing

Research &development programmes are also investigating the modification of braze alloys by the addition of a ceramic reinforcement. This reinforcement provides a joining medium with a coefficient of thermal expansion (CTE) between that of ceramics and metals, and also gives the joint improved strength owing to the introduction of a second phase ie an in situ metal matrix composite. The ability to tailor the CTE of the joining medium is of greater interest. The additional joint strength is a bonus as this raises the possibility of designing the braze to accommodate thermal stresses that would otherwise build up during the joining process as shown in Chart 3.

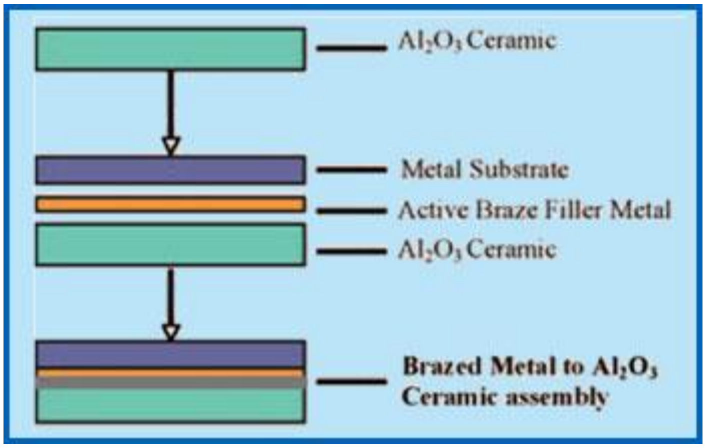

Chart 3: Active Metal Brazing Process

6. CONCLUSIONS

Looking at the field of ceramic joining processes as a whole, techniques have evolved from derivations of metal and plastic joining methods into discrete technologies. However, improvements and modifications to these existing technologies are still required to make them more readily adaptable. In association with this, the selection of the appropriate material and joint design are critical factor when developing joining technologies. Currently active metal brazing is the most advanced technique for joining ceramics to metals and is widely used in defense applications.

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