APPLICATIONS OF SOLID-STATE DIFFUSION BONDING

This article outlines five categories of applications of Solid-State Diffusion Bonding (SSDB).

Amir A. Shirzadi. The Open University, Cambridge Joining Technology.

Category 1: Bonding alloys and composites which are prone to deterioration and decomposition at high temperatures, e.g. when close to their melting points during fusion welding processes.

Nickel and cobalt based superalloys exhibit outstanding strengths at high temperatures. The exceptionally high creep resistance and toughness of superalloys are attributed to their complex microstructures. Great care is required during casting, forming and heat treatment of them to ensure obtaining and maintaining the required microstructures. For the same reason, fusion welding processes can significantly damage the microstructure of the superalloy at and adjacent to the weld line, resulting in inferior mechanical properties.

Diffusion bonding, with or without an interlayer, can be carried out at temperatures well below the melting point of superalloys and therefore the original microstructure and mechanical properties of the superalloy are maintained. Figure 1 shows that near-perfect joints, free from microstructural segregations and defects, can be achieved by diffusion bonding process.

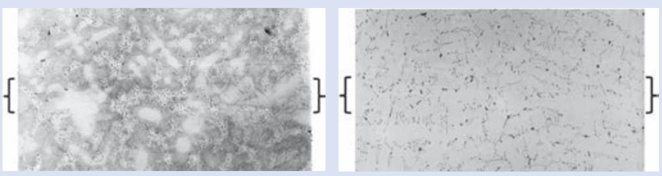

Figure 1: Virtually invisible joints in diffusion bonded nickel superalloy C1023 (left) and cobalt superalloy PWA647 (right). Braces show approximate locations of the joints [Ref. 1]

Diffusion bonding has a large number of applications in the aerospace sector. Example cases are: the fabrication of titanium-based fuel tanks for fighter aircrafts and laminated fan blades for large turbofan jet engines as shown in Figure 2.

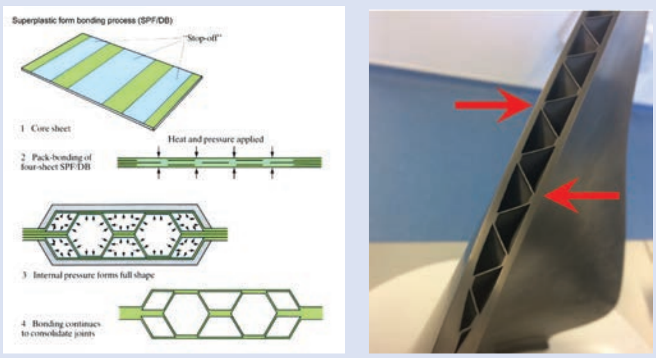

Figure 2: Large fan blades for jet engines are fabricated by diffusion bonding followed by superplastic forming

Category 2: Joining dissimilar alloys with different thermo-physical characteristics, e.g. aluminium to steel which have about 900 °C difference in their melting points.

Joining dissimilar alloys has many applications for fabricating complex bi-material components which allows one component to exploit the benefits of two different materials. For instance, key structural materials used in manufacturing aircrafts are aluminium, titanium, steel and superalloys which are not weldable to each

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other using conventional welding processes. Figure 3 shows examples where diffusion bonding led to successful joining of dissimilar alloys. The example shown are:

i. Top left: creep-test piece, after failure, made of stainless and high temperature resistant steels

ii. Top right: bonded steel-titanium rods which have been subjected to bending and torsion loads

iii. Bottom: steel-aluminium flanges used in ultra-high vacuum X-ray tubes.

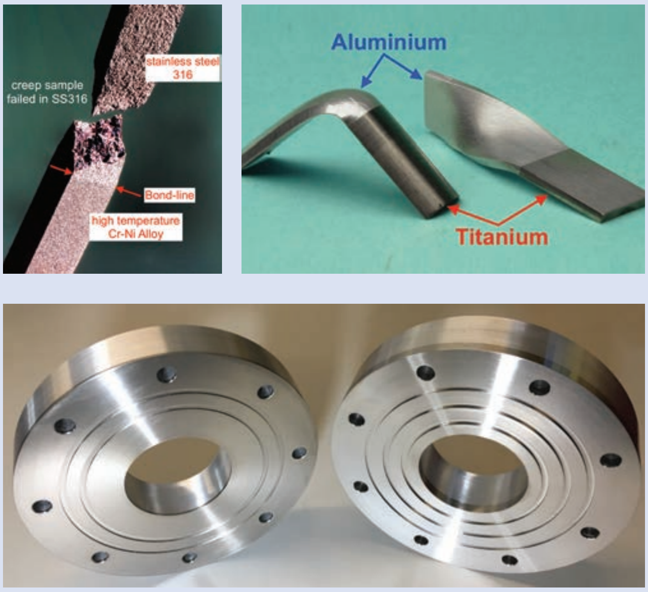

Figure 3: Bi-material components made by diffusion bonding

Category 3: Joining alloys and composites to ceramics, e.g. sapphire to titanium.

There are many engineering applications for joining ceramics and metals using the most common joining method, which is brazing using commercial filler metals. However in certain cases, where a direct joint is required, without a filler metal, then solid state diffusion bonding could be the only option. Figure 4 shows a sapphire diffusion bonded to an aluminium alloy as a part of an optical product. Joining sapphire to titanium and steel is also of interest in manufacturing inspection windows of Tokamak fusion reactors.

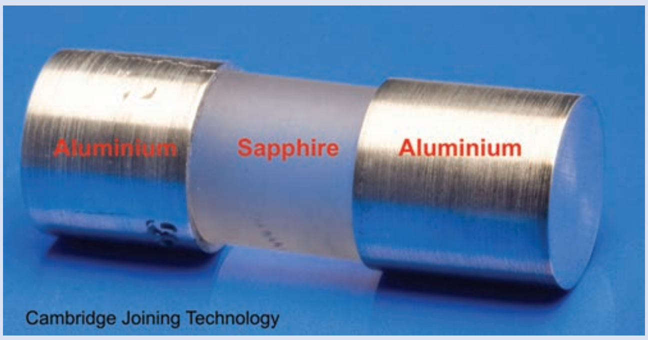

Figure 4: Direct Diffusion bonding sapphire to aluminium without a need for interlayer or brazing filler metal

Category 4: High-precision joining components where the required dimensional tolerances cannot be achieved by post-bonding machining, e.g. microwave filters and duplexers.

Although there are many options for welding structural alloys such as steels and aluminium alloys, extremely close dimensional requirements can be achieved only by solid-state bonding processes. For example, in microwave filters and duplexer used in telecommunications the formation of any fillet at the joint interface would deteriorate the quality of the output signals. Figure 5 shows a high-precision mould, free from any fillet or undercut, made by diffusion bonding stainless steel.

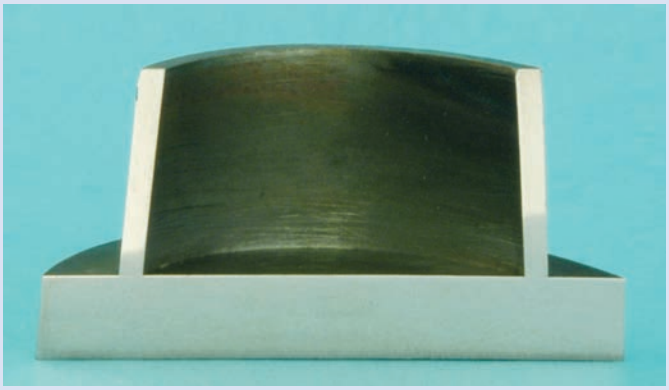

Figure 5: Cross-section of a stainless steel tube, diffusion bonded to a steel plate without the formation of any fillet at the joint

Category 5: Additive Manufacturing (AD) or more precisely Laminated Object Manufacturing (LOM) by diffusion bonding, e.g. Printed Circuit Heat Exchangers (PCHEs).

Perhaps the largest application of diffusion bonding by volume is in manufacturing compact laminated heat exchangers. The chemically etched plates containing channels are stacked in a certain order and diffusion bonded at the same time. This family of heat exchangers, also known as Printed Circuit Heat Exchangers (PCHEs), are considerably smaller and more efficient that conventional "shell & tube" heat exchangers. Figure 6 shows compact heat exchangers, with integrated leak-detection system, made by solid state diffusion bonding of stainless steel without using any interlayer or flux.

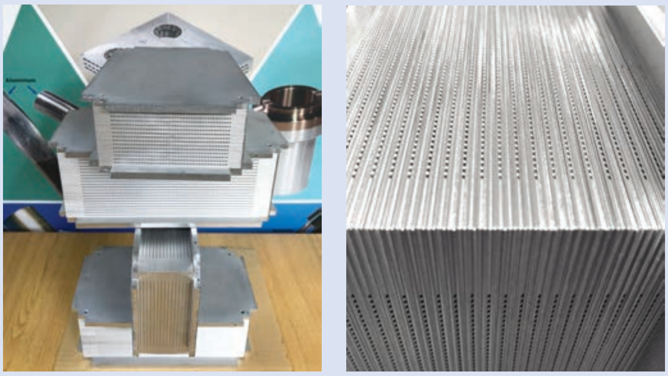

Figure 6: Laminated Object Manufacturing (LOM) of heat exchangers, filters and reformers by diffusion bonding of plates containing chemically-etched channels

Reference:

[1] Shirzadi A.A. and Wallach E.R., New method to diffusion bond superalloys, Science and Technology of Welding and Joining, 2004, Vol. 9, No. 1, pp 37-40. (80%) - https://doi.org/10.1179/136217104225017125