Diffusion welding (bonding)

16.1 introduction

Although this process was developed in the 1970s as a modern Welding technology, the principle of diffusion bonding dates back centuries to when goldsmiths bonded gold over copper to create a product called filled gold. First, a thin layer of gold foil is produced and placed over copper, and a Weight is placed on top of the foil. Finally, the assembly is placed in a furnace and left until a strong bond is obtained; hence, the process is also called hot-pressure welding (HPW).

Is only one of many solid-state joining processes wherein joining is accomplished without the need for a liquid interface (brazing) or the creation of a cast product via melting and resolidification (welding). That produces solid-state coalescence between two materials under the following conditions:

1. Joining occurs at a temperature below the melting point , *T*M
2. Coalescence of contacting surfaces is produced with loads below those that would cause macroscopic deformation to the part.
3. A bonding aid can be used, such as an interface foil or coating ,to facilitate the bonding.

Thus, diffusion bonding facilitates the joining of materials to produce components with no abrupt discontinuity in the microstructure and with a minimum of deformation.

It should be noted that the preferred term for this process, according to the American Welding Society, is diffusion *welding.* However, because diffusion *bonding* is used more commonly in industry. Figure(1)

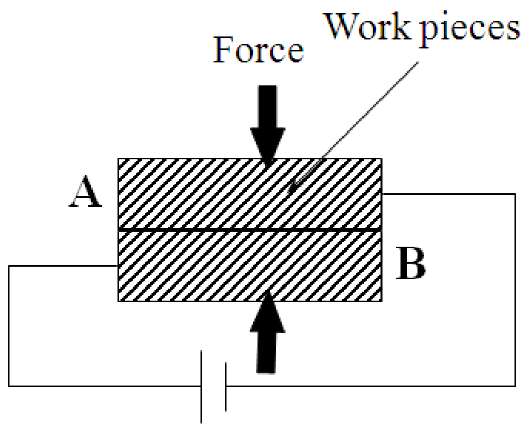


Figure (1) representation of diffusion welding using Electrical resistance for heating

The bonded interface in diffusion welding has essentially the same physical and mechanical properties as the base metal. Its strength depends on:
(a) Pressure, (b) temperature, (c) time of contact, and (d) how clean the faying surfaces are**.**

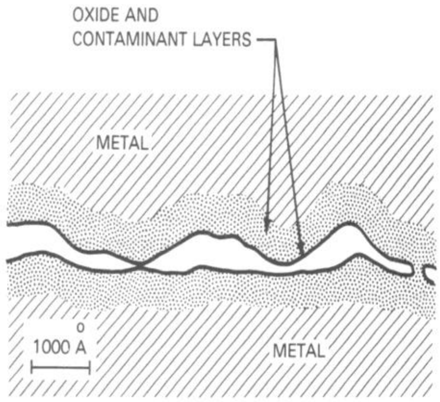
Diffusion bonding generally is most suitable for joining dissimilar metals. It also is used for reactive metals (such as titanium, beryllium, zirconium, and refractory metal alloys) and for composite materials such as metal-matrix composites. Diffusion bonding is also an important mechanism of sintering in powder metallurgy. Because diffusion involves migration of the atoms across the joint, the process is slower than other Welding processes.

16.2 Diffusion Bonding Process

The DB process, that is, the application of pressure and temperature to an interface for a prescribed period of time, is generally considered complete when cavities fully close at the faying surfaces. Relative agreement is found for the mechanisms and sequence of events that lead to the collapse of interface voids, and the discussion below describes these metallurgical processes. Although this theoretical understanding of the DB process is universally applicable, it should be understood that parent metal strength is only approached for materials with surface conditions that do not have barriers to impede atomic bonding such as the absence of surface oxides or absorbed gases at the bonding interface.
In practice, oxide-free conditions exist figure (2) ,only for a limited number of materials. Accordingly, the properties of real surfaces limit and impede the extent of diffusion bonding. The most notable exception is titanium alloys, which, at DB temperatures greater than 850 °C (1560 °F), can readily dissolve minor amounts of adsorbed gases and thin surface oxide films and diffuse them away from the bonding surfaces, so that they will not impede the formation of the required metallic bonds across the bond interface
Similarly, the joining of silver at 200 °C (390 °F) requires no deformation to break up and disperse oxides, because silver oxide dissociates completely at 190 °C (375 °F). Above this temperature, silver dissolves its oxide and also scavenges many surface contaminants. Other examples of metals that have a high solubility for interstitial contaminants include tantalum, tungsten, copper, iron, zirconium, and niobium. Accordingly, this class of alloy is easiest to diffusion bond.
A second class of material, that is, metals and alloys that exhibit very low solubility for interstitials (such as aluminum-, iron-, nickel-, and cobalt-base alloys) are not readily diffusion bondable. Special consideration must be given to remove surface barriers to atomic diffusion prior to joining and subsequently prevent their reformation during the joining process.

This is not an easy processing matter. Accordingly, the potential for high-strength bond interfaces for alloys with low interstitial solubility should be considered on an individual alloy basis.

Figure (2)



16.3 Mechanism of Diffusion Bonding

In diffusion bonding, the nature of the joining process is essentially the coalescence of two atomically clean solid surfaces. Complete coalescence comes about through a three-stage metallurgical sequence of events. Each stage, as shown in Fig. 2, is associated with a particular metallurgical mechanism that makes the dominant contribution to the bonding process. Consequently, the stages are not discretely defined, but begin and end gradually, because the metallurgical mechanisms overlap in time. During the first stage, the contact area grows to a large fraction of the joint area by localized deformation of the contacting surface asperities. Factors such as surface roughness, yield strength, work hardening, temperature, and pressure are of primary importance during this stage of bonding. At the completion of this stage, the interface boundary is no longer a planar interface, but consists of voids separated by areas of intimate contact. In these areas of contact, the joint becomes equivalent to a grain boundary between the grains on each surface. The first stage is usually of short duration for the common case of relatively high-pressure diffusion bonding.

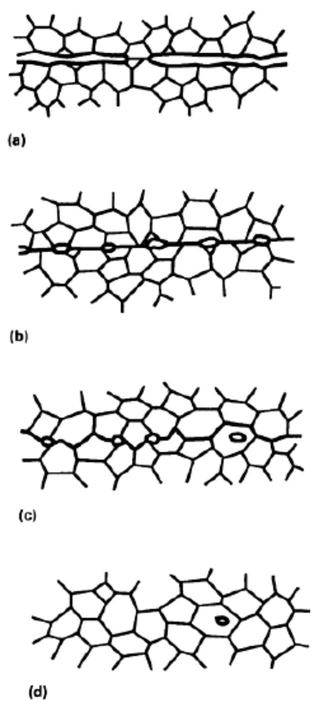


Figure (3) shows the mechanism of diffusion bonding

During the second stage of joint formation, two changes occur simultaneously. All of the voids in the joints shrink, and most are eliminated. In addition, the interfacial grain boundary migrates out of the plane of the joint to lower-energy equilibrium. Creep and diffusion mechanisms are important during the second stage of bonding and for most, if not all, practical applications, bonding would be considered essentially complete following this stage. As the boundary moves, any remaining voids are engulfed within grains where they are no longer in contact with a grain boundary. During this third stage of bonding, the voids are very small and very likely have no impact on interface strength. Again, diffusional processes cause the shrinkage and elimination of voids, but the only possible diffusion path is now through the volume of the grains themselves.

Although diffusion welding is used for fabricating complex parts in low quantities for the aerospace, nuclear, and electronics industries, it has been automated to make it suitable and economical for moderate-volume production. Unless the process is highly automated, considerable operator training and skill are required.