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The importance of interlayers in diffusion welding - A review

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Abstract

During the last few years diffusion welding has become significant attention regarding its suitable applications in comparison to traditional welding techniques. Bonding of dissimilar materials has always been a challenging task due to poor control on grain size and sensitive mechanical properties that could have been made by joining with traditional welding techniques. Moreover, joining dissimilar materials such as Aluminum/steel, metal/glass, Aluminum/copper had been achieved with the usage of diffusion welding. This work presents a review of literature regarding the importance of diffusion welding and influence of interlayers in diffusion welding. Additionally, this paper provides different examples and applications of diffusion welding. Main advantages of this technique are, clean and undamaged exterior parts of weld, power savings, stable and strong bond, time efficiency.

Keywords: Diffusion welding; Copper interlayer; Silver interlayer; Nickel interlayer; Titanium interlayer

1. Introduction

Diffusion Welding is a solid-state welding process, and it provides a novel joining process for similar and dissimilar metals. However, joining of dissimilar metals provides significant advantages in the design and manufacturing of many products. Pressure is applied on two metals with cleaned surface at a temperature below the melting point of the metals. Thus, bonding can occur in their interface atoms [1,2].

Joining and face contacts are improved by interlayers. Electrolysis, thermal spraying and thin foils deposit as interlayers. Mostly Ni and Cu are used, because of diffusivity properties; however interlayers do not have to be used. [3,4]. This article focuses on the importance of interlayers in diffusion welding. Interlayer mechanism is shown in Fig. 1.

Recently, interlayers are getting more useful in diffusion welding applications. Although interlayers give advantages in joints, wrongly chosen interlayer can significantly decrease strength of joints. Main reasons for the use of interlayers are given as; to minimize the formation of intermetallics at the weld interface and to increase the compatibility for joining dissimilar metals.

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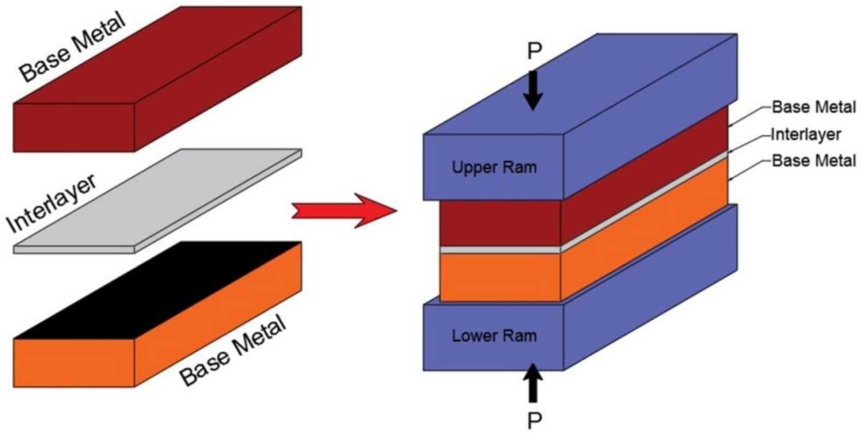

Figure 1: Processing system of diffusion welding

2. Theoretical background

Diffusion welding is getting more applicable for aerospace industry, and it is also used for different applications which are still in advanced development, such as fabrication of honeycomb, turbine components, rocket engines, structural members, composites and laminates [5,6]. The applications of diffusion welding should increase in the next years thanks to additional research and education of process engineers.

Diffusion welding is also known as a recent, non-conventional joining process that has attracted considerable interest of researchers in recent times [6], and it is one of the *Solid State Welding (SSW)* process [7]. According to literature research, many dissimilar metals have been welded by SSW, as well [8,9,10].

There are also some parameters which affect the bonding during diffusion welding process. Diffusivity can be expressed as a function of temperature as follows:

$$D = D_o e^{-Q/kT}$$

where

D = *Diffusivity*, the diffusion coefficient at temperature T;

D_o = A constant of proportionality;

e = An exponential value defined mathematically;

Q = Activation energy for diffusion;

T = Activation temperature;

k = Boltzmann's constant.

It is apparent from the above equation that the diffusion-controlled processes vary exponentially with activation energy and temperature for diffusion.

Table 1: diffusion welding parameters for dissimilar metal couples [11]

Metal 1	Metal 2	Interlayer	Temperature (°C)	Pressure (N/mm^2)	Time (minutes)
Copper	Molybdenum	-	900	7.35	10
Copper	Steel	-	900	04.9	10
Copper	Nickel	-	900	14.7	20
Copper	Copper	-	800-850	4.9-6.9	15-20
Titanium	Nickel	-	800	09.8	10
Titanium	Copper	Molybdenum	950	04.9	30
Titanium	Copper	Niobium	950	04.9	30
Titanium	Copper	-	800	04.9	30
Molybdenum	Molybdenum	Titanium	915	6860	20
Molybdenum	Steel	-	1200	04.9	10
Tungsten Tantalum	Tungsten	Niobium	925	6860	20
Niobium	Tantalum	Zirconium	870	-	-
Zircalloy-2	Niobium	Zirconium	870	-	-

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Steel	Zircalloy-2	Copper	1040	20.6	30-120
Beryllium	Aluminum	Copper	550	04.9	10
Copper	Beryllium	68-Ag-27	800	-	30
Kovar	Copper	Cu-10-ln	-	-	-
Steel	Kovar	-	1000-1110	24.5-10.6	20-25
Steel	Cast-iron	-	850-950	14.7	5-7
	Aluminum	-	500	7.35	30

In Table 1, diffusion welding parameters for metal couples have been established. The parameters include temperature, pressure and time. Also, interlayers for different metals were given.

2.1 Dissimilar metals bonded by diffusion welding

Bilgin [12] bonded Ti-6Al-4V/304L stainless steel using *copper interlayer* by diffusion welding at 830, 850 and 870°C temperature, 1 MPa pressure, for 50, 70 and 90 minutes under the argon gas shielding. Mechanical properties and microstructure analyses were carried out on the bonded samples.

Kundu [13] bonded Ti/304 stainless steel using *copper and nickel interlayers* by diffusion welding. As a result of experimental studies, bonded samples using copper interlayer obtained strength of 318 MPa, however bonded samples using nickel interlayer obtained strength 302 MPa.

Kejanli [14] studied on bonding $Ti_{45}Ni_{49.6}Cu_{5.4}$ composite using *Cu-Ni interlayer* by diffusion welding. Composite materials were produced with approximately 45 µm powders.

Berrana [15] investigated on bonding aluminum and titanium using *copper and silver interlayers* by diffusion welding at 750°C, 3 MPa pressure, and for 10 and 60 minutes. Maximum hardness measurement was obtained at 750°C for 60 minutes. Berrana [16] studied on bonding WC-Co and Ti-6Al-4V alloy using *silver interlayer* by diffusion welding. 825 and 850°C temperature, 15 and 30 minutes and 2 MPa pressure were chosen as diffusion parameters. Bonded samples were subjected to shear test, microhardness and microscopic analyses. The best bonding occurred in the sample processed at 850°C for 30 minutes.

Sabetghadam [17] bonded stainless steel and copper using *nickel interlayer* by processing at 800-950°C, 12 MPa pressure for 60 minute. The interlayers of bonded samples were subjected to SEM, optic microscope, X-Ray and EDS analyses. As a result of this study, Fe-Ni, Fe-Cr-Ni and Fe-Cr were obtained in the diffusion interlayers.

He [18] studied on bonding Ti-6Al-4V and stainless steel (X8CrNi 18 10) using *nickel interlayer* by diffusion welding. TiFe, $TiFe_2$ and TiC which are brittle and tough compounds can be reduced by using nickel interlayer. In high temperatures, it is observed that some brittle intermetallic phases (TiNi, Ti_2Ni, $TiNi_3$, etc.) occurred in Ti and Ni interfaces. In low temperatures, TiNi layer obtained and joining of interface are determined to be weak.

Kliauga [19] bonded Al_2O_3 and 304 stainless steel using *Ti interlayer* by diffusion welding, and investigated on microstructure of interfaces. In this study, 50 µm thickness of α-Ti insisted on diffusion of Al and O into titanium in Al_2O_3 and Ti interfaces.

Travessa [20] bonded Al_2O_3 and 304 stainless steel using *Ti interlayer* by diffusion welding at 700-900°C. They observed that Ti_3Al is obtained in the interface between Ti and Al_2O_3. Maximum shear strength obtained by using Ti interlayer with a thickness of 0.5 mm is closed to 20 MPa.

Ghosh [21] succeeded to bond pure titanium to 304 stainless steel at temperatures of 850, 900 and 950°C for holding time of 2 hours by applying 3 MPa pressure without using interlayer. Maximum strength (222 MPa) is obtained in the samples processed at 850°C. In the higher temperatures, lower strength is obtained due to extreme growth of grain size.

Akca [22] studied on bonding Ti-6Al-4V alloy and pure aluminum by diffusion welding without using interlayer. Samples were processes at 520-680°C for 30, 45 and 60 minutes under the argon gas shielding. The processed samples were subjected to SEM, optic microscope, tensile and microhardness analyses.

Fidan [23] bonded aluminum and copper couples by diffusion welding under the argon gas shielding. Bonded and obtained interphases are investigated by using determined optimum bonding conditions.

Rahman and Cavalli [24] have diffusion bonded commercially pure titanium using silver and copper interlayers and without any interlayer. The maximum tensile strength achieved was 160 MPa, 502 MPa, and

382 MPa when Ag, Cu and no interlayer were used, respectively.

2.2 Copper interlayer

Copper is important commercial material which often is used at temperatures where diffusion processes strongly affect their properties. Significant changes in mechanical properties can occur through surface alloying, compositional changes at interfaces, and interface degradation resulting directly from diffusion.

Copper is a good conductor of heat. This means that if one end of a piece of copper is heated, the other end will quickly reach the same temperature.

Many metallurgical processes such as creep, precipitation, ageing, and corrosion are diffusion-limited. Other important diffusion effects include homogenization of alloys, diffusional breakdown of protective films, permeability of thin-walled tubing, and diffusion bonding.

3. Conclusions

The purpose of this review article was to investigate about effect and importance of interlayer in diffusion welding. In dissimilar metal combinations, such as different aluminum alloys welded to one another or to metals such as copper or steel, a brittle intermetallic layer can form at the weld interface. In order to minimize the formation of these intermetallics a thin-layer of Ti, Ag, Cu and Ni is mostly used according to the literature researches. In some circumstances, other interlayers can be used; however the best results were obtained with Cu interlayer. The main advantage of copper interlayer lies in its high thermal conductivities and diffusivity, which allows for higher heat fluxes. It is also observed that bonding of dissimilar metals is possible without using interlayers in diffusion welding. In the industry, it is important to take care of reducing cost of processes. Thus it is thought that using of interlayer is not vitally necessary.

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