MATERIALS SELECTION IN BRAZING AND SOLDERING PROCESSES

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Abstract: Brazing and soldering require the application of a number of scientific and engineering skills to produce joints of satisfactory quality and reliability. Brazing employs higher temperatures than soldering, but the fundamental concepts are similar, particularly with respect to metallurgy and surface chemistry. Brazing and soldering are joining processes performed at temperatures below the base material solidus temperature. To fill the joint, the liquid filler metal must spread through the joint gap by capillarity or coat the substrate by spreading.

Keywords: brazing, soldering, materials.

1. INTRODUCTION

Capillarity and spreading are related to the balance of surface tensions, which determines the wetting and spreading behavior of a liquid on a solid. Both wetting and spreading are results of interfacial reactions (physical and chemical reactions). The influence of material selection, joint design, and surface conditions on the mechanical properties and corrosion resistance of a brazed joint will be discussed below.

There is no precise definition of brazeability and solderability of a material. These properties are related to how easily a material can be joined, how closely a joint can fit its design function (mechanics, corrosion, electrical contact, and so on), and the most suitable joining process. As an example, in electronic applications solderability involves not only the soldering process characteristics but also the effect of heating on the electronic component characteristics.

2. WETTING AND SPREADING

Wetting is a surface phenomenon related to the balance of the solid-liquid surface tension, γ_{SL}, the solid-vapor surface tension, γ_{SV}, and the liquid-vapor surface tension, γ_{LV}. The contact angle, θ, between the solid and the liquid is defined in equilibrium conditions as the angle between the vectors that represents the liquid-vapor surface tension and the solid-liquid surface tension. The relationship between the contact angle and the surface tensions is given by the Young-Dupré equation:

$$\gamma_{LV} \cdot \cos\theta = \gamma_{SV} - \gamma_{SL} \tag{1}$$

A liquid is said to wet a solid when the contact angle is less than 90°. In this case, for constant γ_{LV} the solid-vapor surface tension is greater than the solid-liquid surface tension. On the other hand, if the solid-vapor surface tension is lower than the solid-liquid surface tension, the contact angle is greater than 90° and the liquid will not

wet the solid. Figure 1 shows a wetting and a nonwetting system in a joint. In neither case did a reaction layer form between the solid and the liquid.

Fig. 1 Schematic showing relationship of contact angle to surface tension:
a - wetting system. b - nonwetting system

Spreading is a dynamic process related to the contact angle θ and can be described as an increase in the liquid surface and the interfacial area, ΔA, with time. Based on Fig. 2, a liquid is said to completely spread over a solid surface when the contact angle tends to 0° (Fig. 2 a). Alternatively, spreading is considered to proceed when the liquid surface area increases to a maximum, even if θ is greater than 0° (Fig. 2 b). Rate of spreading can be inhibited by the liquid inertia and/or the liquid viscosity.

Fig. 2 Schematic showing a liquid spreading through a solid surface with θ< 90°:
a - $\theta_1 = 0°$; b - $\theta_2 = \theta_{echil}$.

From Eq 1, $\gamma_{LV} \cdot \cos\theta$ can be considered as a resistance force that opposes a liquid to wet a solid, and $(\gamma_{SV} - \gamma_{SL})$ is a driving force for wetting. If $\gamma_{LV} \cdot \cos\theta$ is greater than $(\gamma_{SV} - \gamma_{SL})$, no wetting or spreading will occur. So it is important to decrease $\gamma_{LV} \cdot \cos\theta$ and/or to increase $(\gamma_{SV} - \gamma_{SL})$ by means of a flux, a filler metal, or a suitable brazing atmosphere. γ_{LV} and γ_{SV} decrease when a deoxidation reaction takes place at the liquid and solid surfaces. γ_{SL} can be reduced by promoting a deoxidation reaction via alloying elements in the filler metal (such as phosphorus in BCuP filler in contact with a copper substrate), formation of a reaction layer, or adsorption of a chemical element at the solid-liquid interface. Figure 3 shows the effect of the atmosphere and filler metal composition on the surface tensions for a Cu-BCuP system.

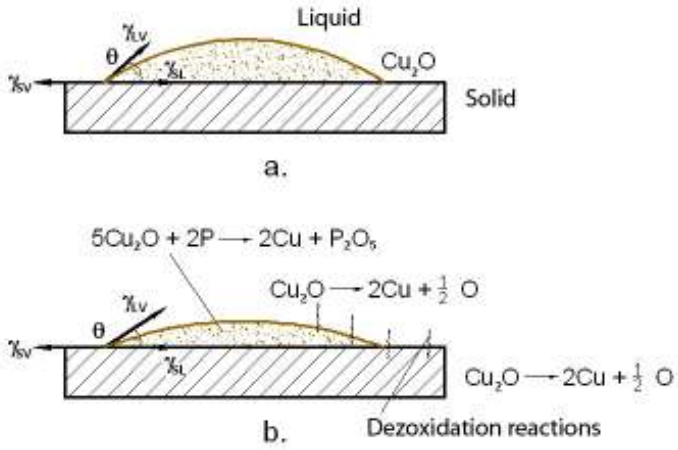

Fig. 3 Schematic showing effect of the surrounding medium and the composition of the filler metal on the wetting and spreading behavior of copper-BCuP system.
a - neutral or oxidizing medium; b - deoxidizing medium

3. INTERFACIAL REACTIONS

During brazing, the molten filler metal often reacts with the base metal. The product is a reaction layer that is sometimes too thin to be observed by optical microscopy. In fact, this layer modifies the wetting and spreading behavior of the liquid filler metal in contact with the base metal. Figure 4 shows the interfacial reaction during the brazing process.

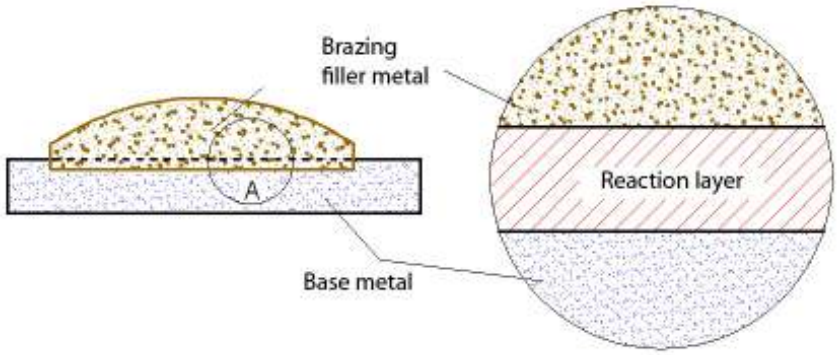

Fig. 4 Reaction layer formation during the brazing process

When an interfacial reaction occurs between the base metal and the liquid filler, the free energy of the reaction per unit area and unit time (ΔGr) should be included in Eq 1, as follows:

$$\gamma_{SV} - (\gamma'_{SL} - \Delta G_r) = \gamma_{LV} \cos\theta \tag{2}$$

Due to a change in the solid-liquid interface by a chemical reaction, γ'_{SL} is lower than γ_{SL} of Eq 1. The variables γ'_{SL} and ΔG_r will increase the driving force for wetting. If the driving force is greater than $\gamma_{LV} \cdot \cos\theta$, spreading will occur until the liquid has reacted completely with the solid.

4. LIQUID FILLER FLOWABILITY

Joint clearance is an important factor in the brazeability or solderability of a joint. The BAlSi and BMg filler metals require larger clearances, while the BCu, BAu, BAg, and BCuP filler metals require smaller gaps. This difference can be related to the difficulty with which the first two filler metal groups wet and spread over a solid surface.

The flowability of a liquid filler metal on a solid surface is related to the equilibrium conditions expressed through Eq 2, the dynamic properties such as liquid viscosity, and interfacial reaction kinetics, if applicable. So it is desirable that a filler metal has: high wettability as described by Eq 2, low viscosity and faster interface reaction kinetics. *Joint design* also affects filler metal flow.

5. JOINT CLEARANCE

The effect of joint clearance on the behavior of a joint is about the same whether the joint is brazed or soldered. When shear strength is plotted as a function of joint clearance, three different regions can be identified. At small clearances, region 1, the joint strength decreases as the clearance diminishes. The number of pores and the lack of joint filling caused by improper flow of the molten filler metal may be responsible for the lower shear strength observed. Surface discontinuity and/or entrapped flux are other factors that contribute to the joint performance. If

intermetallic compounds form at the interface, a small joint clearance will invariably result in a higher volume fraction of brittle compounds, which degrade the joint properties.

6. MUTUAL DISSOLUTION AND EROSION, VAPOR PRESSURE AND FLUXES

In the presence of the liquid filler metal, base metal dissolution can occur. Depending upon the mutual solubility of the base metal and the filler metal, excessive dissolution or erosion can result. Additionally, the alloying elements found in the filler metal may migrate into the base metal through solid-state diffusion or liquid metal grain boundary penetration.

The vapor pressure of an element increases with increasing temperature. Furthermore, decreasing the surrounding pressure, such as in a vacuum, further increases the vaporization loss. This will cause variations in the chemical composition of the filler metal. As a consequence, the flowing behavior of the filler metal can be impaired. Metal vaporization may also promote porosity formation in the joint.

Chemical reactions typically occur between the surface oxide and the active components of the flux. The surface oxide can undergo a reduction reaction that results in the formation of a soluble compound, as exemplified below:

$$(OM)_S + (FLUX) \rightarrow M_S + O + \ldots \tag{3}$$

$$(OM)_S + (FLUX) \rightarrow M_S + (MO \cdot FLUX)_{s.l.} \tag{4}$$

$$(OM)_S + (FLUX) \rightarrow M_S + (MO \cdot VEHICLE)_{s.f.} \tag{5}$$

where MO is the metal oxide, M is the metal, and O is oxygen. The subscript surf indicates that the reaction is located at the surface. (MO · FLUX) and (MO · VEHICLE) represent metal oxides dissolved in the flux or vehicle. Equation 3 represents a reduction of a surface oxide by a flux, resulting in a metal at the surface plus the evolution of oxygen. Equations 4 and 5 represent a reduction of a surface oxide by a flux succeeding in a metal at surface and the oxygen soluble in the vehicle flux (Eq 4) or in the flux (Eq 5).

The chemical activity of a flux is strongly dependent on temperature and on the properties of a flux, such as thermal stability, activation temperature, and deactivation temperature that characterize the activation temperature range. Suitable joining processes require that the flux components be stable throughout the joining cycle. They should not evaporate or decompose. For example, in applications in which the boiling point of the flux vehicle is lower than the joining temperature, the flux is thermally stable and able to protect the clean surface from reoxidation. On the other hand, the flux vehicle may have a high boiling point and remain intact on the part surface. The liquid flux vehicle assists the flux solder to act as a physical barrier that ensures protection of the clean surface against reoxidation.

The activation temperature range is defined as the temperature range at which a flux reaches its maximum chemical activity. The deactivation temperature is the temperature at which the flux breaks down and is no long active. It is important that the joining temperature remains slightly higher than the minimum activation temperature for maximum activity.

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