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Review of the High Vacuum Metal-Metal and Metal-Ceramic Brazing Process

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ABSTRACT
Brazing is a joining process which is extensively used for components fabrication. The significance of this process lies in its ability to join similar or dissimilar metals to metals and metals to non-metals with close coefficient of thermal expansion (CTE). High vacuum brazing is carried out at high temperature to obtain hermetically sealed joints. This technical paper emphasizes on various parameters governing the brazing process, significance of contact angle in promoting wetting and spreading, strength obtained by mechanical testing and braze joint design. Furthermore it discusses various designs of metal-ceramic joining.
Keywords – Active, CTE, hermetically sealed, high vacuum and parameters.

I. INTRODUCTION

The American Welding Society (AWS) defines brazing as “a group of welding processes” which produces coalescence of materials by heating to suitable temperature and using a filler metal having a liquidus above 450^{0}C and below solidus of base metal [1].It differs from welding as it takes place at temperatures below the melting points of the base materials to be joined. Parts that may not be joined at all by other methods can be joined by brazing. The nature of the interatomic (metallic) bond is such that even a simple joint, when properly designed and made, will have strength equal to or greater than that of the as-brazed parent metal or non-metal. Metal as thin as 0.01mm and as thick as 150 mm can be brazed. There are infinite numbers of possible parent metal brazing alloy combinations. The phenomena of wetting and flow of a liquid on the surface of a solid are basic to most models developed to describe the formation of a braze joint. Wetting of the base materials by the braze filler metal is required to provide the bonding needed and is characterized through the thermodynamic concept of capillarity [2]. The braze filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction. The capillary flow depends on the ability of the brazing alloy to wet the parent metals. This property is determined by the relative characteristics of the solid and liquid phases, its measure being the magnitude of the contact angle. The lower the contact angle, the better are the wetting and spreading properties of the brazing alloy, and no capillary flow can take place unless the contact angle is less than 90^0 [3]. Brazing generally generates much less thermally-induced distortion or warpage since a part can be uniformly heated to brazing temperature and therefore, minimizes any type of distortion. Load carrying capacity of the brazed joint is affected by the dimensions of the joint gap and by the design of whole assembly. Brazing processes are employed where welding processes cannot be used viz. value added components, high quality RF systems, carbide tools, UHV components of high energy [4].

1.1 SIGNIFICANCE OF VACUUM FURNACE BRAZING

It is usually a high temperature (typically 927^{0}C to 1232^{0}C), fluxless process using nickel-base, pure copper and less frequently precious BFM.

(i) Advantages of brazing under vacuum conditions
Purity level of atmosphere (vacuum) can be precisely controlled. There is less residual oxygen to contaminate the work piece. The vacuum condition at high temperature results in a decomposed oxide layer, and by doing so improves the base metal wetting properties. It results in minimum distortion because all parts are heated and cooled uniformly at precisely controlled rates. Furthermore, it provides repeatability and reliability of the brazing process.

1.2 MANDATORY CONDITIONS FOR BRAZING

(i) Joining must be without melting the base metal.
(ii) Braze filler metal (BFM) must have melting temperature above 450^{0}C.

(iii) BFM must wet the base metal surfaces and be drawn into or held in the joint by capillary attraction.

1.3 REASONS OF VARIOUS BRAZING PROBLEMS

Violation of one of these fundamentals of brazing causes brazing problems:

(i) Proper design of brazed joint.
(ii) Cleaning and surface preparation of work pieces prior to brazing.
(iii) Proper joint fit up (gap clearance at brazing temperature, flatness, etc.)
(iv) Braze filler metal selection.
(v) Properly designed vacuum furnace brazing cycle (brazing temperature and time, heating and cooling rates, etc.)

1.4 WETTING AND ADHESION

Joining of two materials together requires bonding. The nature of this interaction can be chemical, physical or simply mechanical. Joining processes resulting in physical or chemical bonding such as brazing is ruled by thermodynamic principle of energy reduction. The elimination of two surfaces to form an interface reduces the total energy of the system. When the materials to be joined are dissimilar, there also exists a chemical potential gradient at the interface. Ceramic/metal brazing relies on the ability of a filler metal or alloy to wet the ceramic surface. The wetting by a liquid metal/alloy depends on the magnitude of the surface tension and the reactivity of the species involved. Surface properties, microstructure of the ceramic material and reactivity of the filler alloy in the brazing atmosphere are the main aspects that control wetting. The magnitude of wetting can be evaluated from the contact angle [5].

1.5 BRAZE JOINT DESIGN

1.5.1 Clearance for Vacuum Furnace Brazing: It is the distance between the surfaces of the joint at brazing temperature. Required clearance for silver, gold, copper and nickel braze filler metals at brazing temperature lies between 0.0005 to 0.004 inch. Vacuum brazing requires lower clearances than atmospheric brazing. For vertical joints, clearance should be less than 0.002 inches.

1.5.2 Differential Metal Expansion (DME): With dissimilar metals, the one with the highest expansion coefficient may tend to increase or decrease the clearance.

Calculation of Room Temperature Clearance: Knowing the DME rates for the metals being joined, back calculate from the brazing temperature down to room temperature, to find room temperature clearance.

1.5.3 Effect of Surface Roughness: It may be 32 RMS, 64 RMS or even 125RMS or greater. It adds surface area to the joint which provides countless extra capillary paths for BFM to follow [1].

1.5.4 Design of Joints:

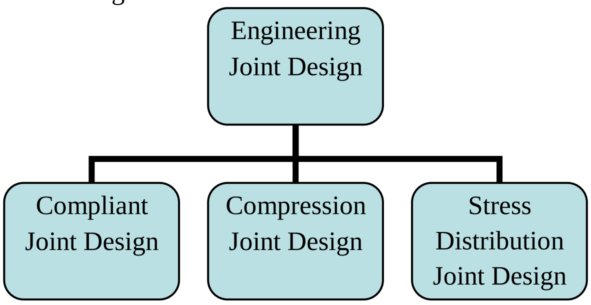

Fig. 1: Taxonomy of Joint Design

Compliant Joint Design (Fig.1): Edge brazing of a metal cylinder to a ceramic face is a popular form of compliant joint. In this case, thermal expansion mismatch is accommodated by the concentric distortion of the metal cylinder. This design can also be obtained by using an interlayer that has a thermal expansion coefficient between those of the ceramic and the metal. This distributes the thermal expansion mismatch and reduces the thermal stress.

Compression Joint Design: In this design, thermal expansion mismatch is used to obtain a reliable joint. This can be obtained by brazing the ceramic member into the metal member. During cooling from brazing temperature to room temperature, the metal member (outside) contracts more than the ceramic member (inside).This results in compressive stress in the ceramic as well as in the joint and the joint strength is increased.

Stress Distribution Joint Design: A ceramic backup can be used to distribute tensile loading on the metal diaphragm [6].

1.6 METAL CERAMIC JOINING

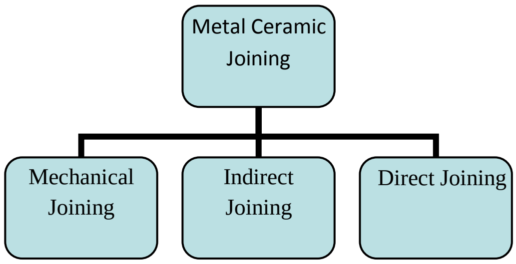

Fig. 2: Taxonomy of Metal Ceramic Joining

Mechanical Joining (Fig 2): It can be done by 3 ways:
(i)Screwing (ii) Fitting (iii) Clamping

Mechanical strength of the metal-ceramic joint in mechanical joining lies between 10 to 50 MPa.

Indirect Joining is classified into two categories viz. Adhesive and Brazing [8]. Structural ceramics which have been brazed are Si_3N_4, SiC, Al_2O_3, AlN and ZrO_2.Mechnical strength of metal-ceramic joint in brazing is approximately 100MPa.

Direct joining of metal-ceramic is carried out by solid state diffusion. Friction welding is an example of solid state joining. Fusion welding is based on localized melting of the metallic component. A laser beam is commonly used as a heating source. Mechanical strength of the joint in fusion welding lies between 50 to 200 MPa .

Problem in Joining of Ceramics by Brazing: Usual BFM do not wet surface of ceramics. The difference in coefficient of thermal expansion of metal and ceramics induces tremendous stress which can lead to cracking of brazed joint [7].

II. ANALYTICAL ANALYSIS

Young's equation is given as

$$\cos \Theta = (Y^{SV} - Y^{SL}) / Y^{LV} \quad (1)$$

Where,

Θ = contact angle

Y^{SV} = solid vapor interfacial energy

Y^{SL} = solid liquid interfacial energy

Y^{LV} = liquid vapor interfacial energy

Average velocity, V, of capillary flow between parallel horizontal surfaces, is given by

$$V = D \gamma \cos \Theta / 6 \eta S \quad (2)$$

where,

D = joint gap

γ= surface tension of BFM

η= viscosity of BFM

Θ = contact angle

S = distance through which the metal has flowed.

Time, t, in which the brazing alloy will flow through the distance S is given by

$$t = 3 S^2 / D \gamma \cos \Theta \quad (3)$$

where, t = time taken by BFM to flow through distance S.

III. OBSERVATIONS

An example of the edge brazing where a copper-clad 430- stainless- steel cap has been brazed on an alumina cylinder is shown in Fig. 3.

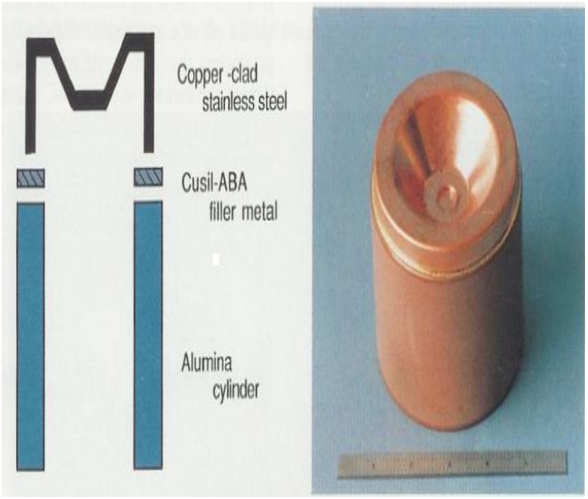

Fig. 3 A schematic cross section of the assembly (left) and the actual brazed sample (right)

An example of the compression joint where a silicon nitride rod is brazed into a hole machined in a 410 stainless steel with Cusil- ABA is shown in Fig. 4.

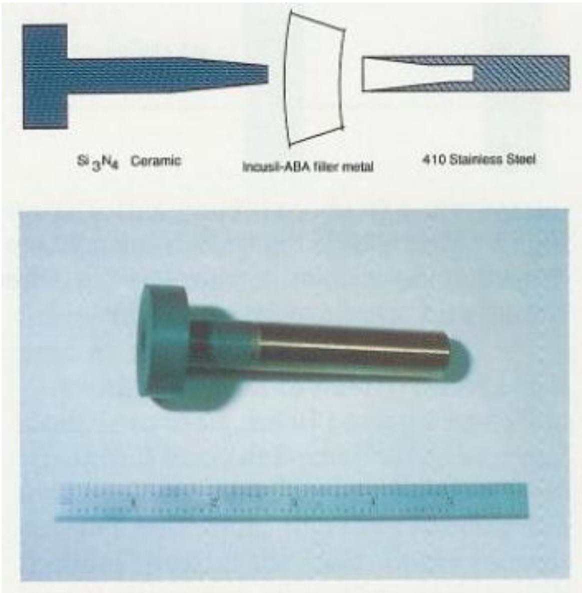

Fig. 4 A schematic cross section of the joint (top) and the actual compression joint (bottom)

An example of the stress distribution joint design where Alloy 42 sheets are brazed on both ends of an alumina cylinder with alumina backup rings is shown in Fig. 5.

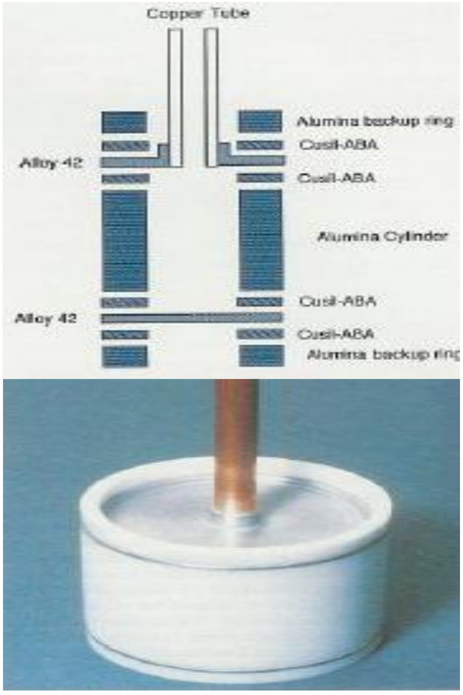

Fig. 5 A schematic cross section of the joint (top) and actual stress distribution joint (bottom).

IV. CONCLUSION

Brazing is a versatile joining process which can be used for joining dissimilar materials. The quality of brazed joints depends strongly on the combination of filler and component materials and also on the processing conditions that are used.

There is a difficulty in joining of metal with ceramics due to large difference in coefficient of thermal expansions (CTE). But this CTE mismatch can be used to obtain a strong joint by selecting proper joint design.

The strength of brazed joint depends upon the wetting of base metal by braze filler metal which in turn depends upon the contact angle.

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