Overview of Brazing Processes for Accelerator Components and Qualification Techniques of Cu-Cu Brazed Joint

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Abstract-*This present study elaborates about the different brazing processes used to join different sections of particle accelerator components made from Oxygen Free Electronic (OFE) Copper. Tough induction brazing, torch brazing has been used conventionally, protected atmosphere brazing carried out in vacuum, inert and reducing atmosphere is mostly used in defense, aerospace, and particle accelerator related fabrication processes. This study also discusses the most influencing brazing process parameters like joint clearance, brazing filler metal, brazing atmosphere, brazing temperature and time and its effect on joint quality. Qualification techniques and metallographic analysis of brazed joints were also discussed.*

Keywords-Protected Atmospheric Brazing, OFE Copper, Brazing Filler Metal, Joint Clearance, Qualification Techniques, Metallography.

I. INTRODUCTION

A particle accelerator is a machine that accelerates elementary particles, such as electrons or protons, to very high energies. Particle accelerators produce beams of charged particles that can be used for a variety of research purposes. Particle accelerators are used to produce the beams of high energies, and useful for various applications in different areas like energy, environment, medicine, industry, security and defense.

Brazing [5] is a joining process whereby a filler metal or alloy is heated to melting temperature above 450°C and distributed between two or more close-fitting parts by capillary action. During brazing, the molten filler metal diffuses into the base metal components. This forms an exceptionally strong, sealed joint. Brazing can be superior [8] to welding because it heats the entire part uniformly, causing less distortion.

1.1 Types of Brazing Process

There are many ways of brazing, and they all differ in the method of applying heat to the braze assembly, in particular, the joint area. These include torch brazing, furnace brazing, and induction brazing.

1.1.1 Torch Brazing

In torch brazing [9], the heating of the joint is accomplished using the flame of a single or multiple gas torches. Multiple torches are used to obtain a uniform heating throughout the joint area. The brazing filler metal may be preplaced at the joint in the form of rings, washers, strips, slugs, powder, or it may be fed manually. Torch brazing is very useful on assemblies that involve heating sections of different mass. Manual torch brazing is particularly useful for repair work. Torch brazing is used when the part to be brazed is too large, or of complex shape, or cannot be heated by the other methods. Following figure 1 shows the torch brazing. important technique, used in Intelligent Transportation System. It is an advanced machine vision technology used to identify vehicles by their number plates without direct human intervention. The system work is generally framed into the steps: Number plate extraction, character segmentation and character recognition. From the entire input image, only the number plate is detected and processed further in the next step of character segmentation. In character segmentation phase each and every character is isolated and segmented. Based on the selection of prominent features of characters, each character is recognized, in the character recognition phase. This system is important in the area of traffic problems, highway toll collection, borders and custom security, premises where high security is needed. Previous works are Vehicle Number Plate Detection (VNPD) system algorithm based on template matching. They have devised an efficient method for recognition of Indian vehicle number plates.

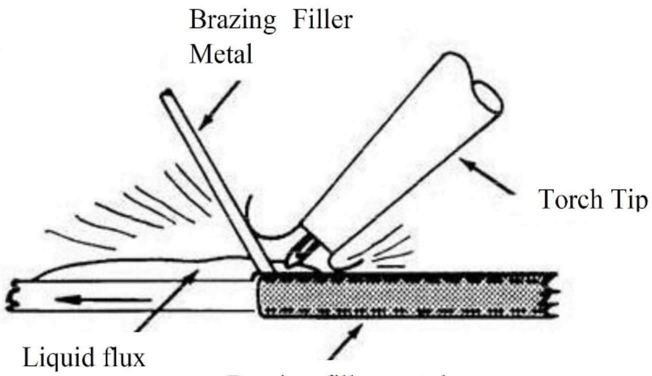

Figure 1: Torch Brazing

1.1.2 Induction Brazing

In induction brazing [9], the heat necessary for brazing is obtained by the induction heating principle. The components to be brazed are placed in the magnetic field of a water cooled coil carrying a high frequency current. This current induces eddy currents in the components. The induced current flow in the surface skin of the body and are concentrated in the area closest to the coil. The depth of the heating depends on the current frequency used. High frequency current produces skin heating in the components while lower frequency current results in deeper heating and is thus recommended for brazing heavier sections. In induction brazing, fluxing may or may not be employed and the filler metal is usually preplaced at the joint.

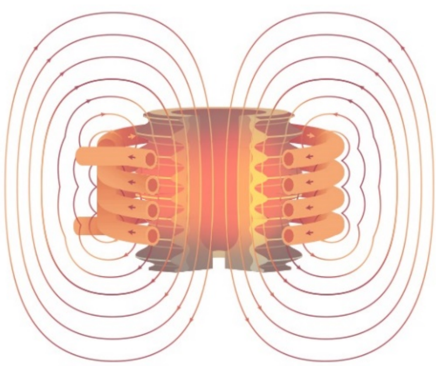
Figure *2*: Induction Brazing

Figure 3 shows the typical coil designs used in the induction brazing process.

The primary advantage of the induction brazing over other brazing processes is its localized heating which minimizes oxidation, distortion and the metallurgical changes like softening of cold worked or heat treated metal. Controlled heat input along with rapid heating rates and automatic mode makes it a high production rate process which can be used in air.

1.1.3 Brazing in Protected Atmosphere

Protected atmosphere brazing [5], [6], [10] is brazing in a dry, inert gas atmosphere. Mostly inert gases like nitrogen, argon, helium are used. The gas is introduced in the critical brazing section of the furnace and flows towards the entrance and exit. This prevents contamination of the atmosphere in the braze section.

In furnace brazing [6], the parent materials are cleaned and placed in a furnace. The parts should be self-jigging and assembled, with the filler materials already placed near or in the joint. The brazing filler material may be in the form of wire, foil, fillings, slugs, powder, paste, tape, and so on. The furnaces are usually of electrical resistance type. Furnace brazing is often done by the use of special atmospheres like hydrogen, helium and argon in the brazing furnace. Furnace brazing is also performed in vacuum during the fabrication of aerospace and nuclear components where entrapped fluxes are not tolerable.

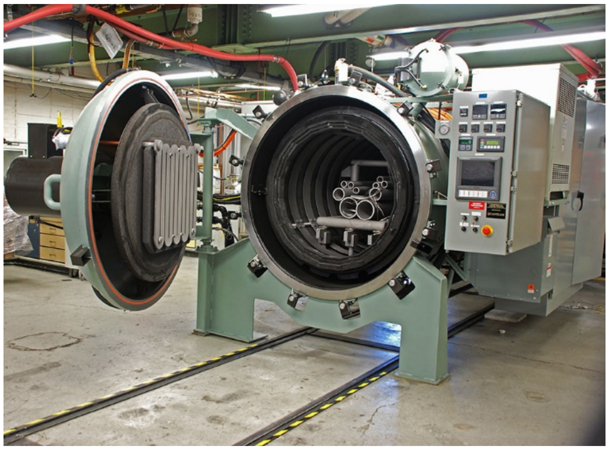
Figure 3: Protected Atmosphere Brazing Furnace

Figure 3 shows an automated furnace brazing set-up in which the parts along with the preplaced brazing filler are joined inside the furnace.

- **Benefits of Protected Atmospheres**

Controlled atmospheres have several advantages [10] over the use of flux. If the job can be done without flux, there is no need for a post-braze cleaning to remove residues. A controlled atmosphere will also prevent the formation of oxides and scale on the part. Therefore, in many applications, parts can be machine-finished prior to brazing, and then go directly to a coating or plating operation without an intermediate cleaning step. Finally, the use of protective atmospheres is the only way to prevent damage from flux contamination produced by some techniques.

❖ Effects of the Gases on Brazed Parts

All components of a protected atmosphere make contributions to the brazing process. Hydrogen [5] is an active agent for the reduction of most metal oxides at elevated temperatures. Hydrogen can cause embrittlement in some materials but is not usually a problem in slow-cooled products such as brazements. Carbon monoxide (CO) is an active reducing agent for some metal oxides such as those of iron, nickel, cobalt, and copper at elevated temperatures, but CO is toxic and must be handled with care. This gas can serve as a source of carbon through cracking in the cooling zone of the furnace to form free carbon on the surface of the brazement. This may be useful in brazing some carbon steels but is undesirable in other applications.

II. INFLUENCING FACTORS IN BRAZING PROCESS

1.2 Joint Clearance

Joint strength [4] depends upon the clearance between the joints. Relationship between joint clearance and joint strength states that with increasing joint clearance strength of brazed joint decreases. Following figure 4 depicts the effect of clearance on the tensile strength.

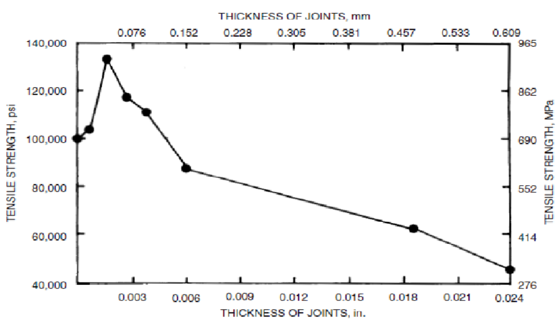

Figure 1: Effect of joint clearance on tensile strength

1.3 Brazing Filler Metals

Brazing filler metals are metals or alloys, have a liquidus temperature above 840°F (450°C) but below the solidus of the base metals. For satisfactory use as a brazing filler metal, it should possess the following characteristics, the ability to spread and adhere to the base materials on which it is used. This is referred to as wetting [5]; Suitable melting point or melting range and fluidity to permit its distribution by capillary action into properly prepared joints; A composition of sufficient homogeneity and stability to minimize the separation of constituents by liquation under the brazing conditions to be encountered; The ability to form brazed joints possessing suitable mechanical and physical properties for the intended service application; and depending on requirements and specifications, the ability to produce or avoid certain interactions between the base metal and brazing filler metal. Brittle inter-metallic compounds [10] or excessive erosion may be undesirable while a higher joint re-melt temperature the temperature to which a completed brazed joint must be raised to separate the joint might be an attribute.

Figure 5 presents the phase diagram for the silver-copper binary system. The solidus temperature line, ADCEB, represents the start of melting for all alloy combinations of silver and copper in the system. The liquidus temperature line, ACB, represents the temperatures above which each of these alloys in the system is completely liquid. At Point C, the liquidus and solidus temperature lines meet, indicating that a particular alloy melts at a constant temperature instead of melting over a range of temperatures. This point is known as the eutectic point. The composition of the alloy at this point, 72% silver and 28% copper, is known as the eutectic composition. At eutectic temperature, melting range is zero. Whole composition melts at single temperature. Hence better joints properties can be found with eutectic alloy. In general alloy with melting ranges are more sluggish than eutectic alloy compositions with respect to flow in a capillary joint.

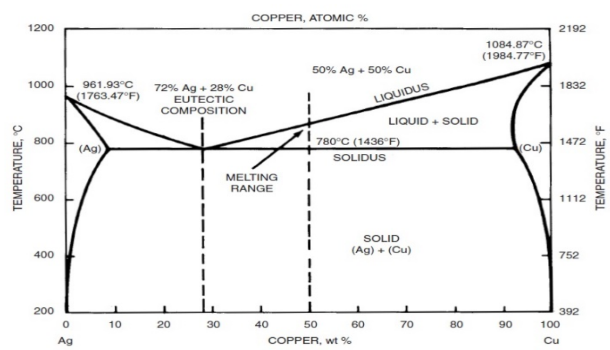

Figure 2: Phase diagram for Silver-Copper binary system

Keeping this in mind, for joining of different sections of accelerator components [1] two brazing filler metals has been used i.e. palladium based PalCuSil-5 BFM at 830-840ºC and silver based BVAg-8 at 810°C. BFM in foil form is used. Brazing is carried out at 10^{-5} torr vacuum pressure. Whereas, Palladium based brazing filler metal [3] i.e. B-Ag68CuPd 807/810 at brazing temperature of 825 °C has also been used.

1.4 Brazing Temperature

Generally, a filler metal with the lowest brazing temperature suitable for the intended service requirements is preferred. Lower brazing temperatures offer several advantages. They minimize the heating effects (e.g., annealing, grain growth, and distortion) on base metals. They also minimize interaction between the base metal and brazing filler metal during brazing, particularly to prevent the erosion of the base metal. They increase the life of the tooling and economize on the heating energy required in the process. To have flow over the base metal, additional thermal energy needs to be supplied. Hence generally 10ºC to 50ºC temperature above the liquidus temperature is selected. Brazing has been carried out earlier at temperature of 790ºC [2] and 810ºC [1].

1.5 Surface Finish of Base Metal

Surface preparation is a very important factor in successful brazing. If the surface of the braze joint is not clean, contamination prevents the proper wetting and flow of the brazing filler metal. Contamination can be caused by oil lubricants and cutting oils as well as by the sodium silicate used in cleaning solutions. To have better flow of molten filler metal in joint, optimum surface finish [4] is required. Micro-scratches on the surface of material provide the pathways to flow of molten filler metal. High surface roughness increases the overall clearance of joint and hence reduces the strength of joint whereas highly smooth surface provides less the pathway for flow of molten filler metal. Surface roughness of 0.8 μm [1] has been used to obtain better flow of molten brazing filler metal in brazing surface.

1.6 Brazing Atmosphere

Ellingham diagram [5] can be used to determine vacuum pressure required to remove the oxides layers formed during the heating in furnace. Vacuum pressure of 10^{-5} torr [1] has been used earlier to successfully reduce the oxides. Reducing Gases like hydrogen [15] has been used in furnace as it eases to remove the oxide layers at elevated temperature and it was observed that joints formed in hydrogen vacuum furnace [15] are sound, void free and having leak rate of less than 5×10^{-10} mbar l/s.

1.7 Brazing thermal cycle

In order to establish reliable thermal cycles [4] for brazing, it is essential to know when the entire workload attains uniformity of the brazing temperatures. Vacuum level, heating/cooling rates, temperature, time etc is to be selected properly. Problems are encounter in vacuum brazing due to incorrect joint design, inappropriate cleaning techniques, faulty fixture design, improper joint fit up i.e. gap clearance at brazing temperature, flatness, squareness, etc. Right brazing filler metal (BFM) selection and its application practices are important to have successful brazing. Two thermal cycles [16] each for Gold based filler metal (50Au/50Cu) and for silver based filler metal (BVAg-8) has been used earlier for OFE Copper to Glidcop joints. Brazing was carried out at 830°C with 3 minutes of soaking time. Two intermediate soaking temperatures, roughly at 500°C and 750°C, are used before attaining the brazing temperatures. This is used to attain temperature uniformity during heating. Heating rate [19] in the range of 1.7 – 6.7 ºC/Min and brazing time of 10 min has yielded in sound joint. Soaking temperature taken as 760ºC.

III. QUALIFICATION OF BRAZED JOINT

ASME Section IX [12] and AWS Standard [13] gives the idea for designing the specimen for tensile and shear test. Qualification will be carried out using ASME Section IX QB. In order to qualify the brazing process, brazing trials are to be taken by selecting influencing process parameters. Standard test specimens have been manufactured by referring these standards. Acceptance criteria for the specimens tested for Tensile Strength is given in ASME Section IX. In order to pass the tension test, the specimen shall have a tensile strength that is not less than the specified minimum tensile strength of the base metal in the annealed condition; If the specimen breaks in the base metal outside of the braze, the test shall be accepted as meeting the requirements, provided the strength is not more than 5% below the minimum specified tensile strength of the base metal in the annealed condition.

IV. CHARACTERIZATION OF BRAZED JOINT

Metallographic evaluation is important to determine thickness of brazement, effect on grain size after thermal cycle, to see formation of reaction layer, micro-cracks and porosity, etc. Standard procedures [6] for Metallography include sectioning of test piece from specimen, mounting with suitable material, grinding polishing, etching of the metallographic specimen and finally microscopic examinations. Care must be taken while carrying out metallography because it involves many steps that can alter the structure observed during examination, leading to erroneous conclusions. Optical Microscopy (OM) [7] can be used for micro-structural analysis while Scanning Electron Microscopy (SEM) [7] can be used to observe the eutectic phase of BVAg-8 in the Cu-Cu brazed joint. Grain boundary diffusion of filler alloy in base metal and thickness of inter-diffusion can be determined along with lack of fusion and porosity check. Leak proof joint is also one of the important requirements of brazed joint. Helium Mass Spectrometer Leak Detection (MSLD) [14] has been widely used to determine leak in high vacuum application. Brazing of photocathode RF gun structures [15] in Hydrogen atmosphere with BVAg-8 filler alloy is carried out earlier where leak rate of 5×10^{-10} mbar $ls^{-1}$is observed, which is acceptable.

V. CONCLUSION

It can be concluded that vacuum and reducing atmosphere with hydrogen gas has been widely used for Cu-Cu joining. Silver based filler metal (Cu-Sil i.e. BVAg-8) has been widely used for joining of different sections of accelerator parts which are made in Oxygen Free Electronic (OFE) Copper. Brazing temperature is selected above the liquidus point of brazing filler metal and below the solidus point of base metal. Better joint quality was observed at 10^{-5} torr vacuum pressure. Reducing atmosphere such as hydrogen gas can be used for ease of removal of oxide film formed on the base metal during the heating cycle. Procedure for the process qualification of brazed joint is broadly discussed in ASME, AWS standard provides the wide information. Destructive tests like tensile and shear testing are used for determining strength of brazed joint. Helium Mass Spectrometer Leak Detection (MSLD) test is used to determine the leak tightness of brazed joint. Metallographic examination is used to study the flow of molten filler metal.

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