Tips for Producing Strong Soldered and Brazed Joints

By using five easy-to-understand steps, dependable connections for more reliable joints ca be made

BY GREG MITCHELL

To ensure durable, leak-free joints, proper soldering and brazing procedures must be in place when joining metal tubes and fittings on appliances, plumbing, and heating, ventilation, air-conditioning, and refrigeration (HVACR) systems — see lead photos.

Yet, too often, many of the critical care procedures are overlooked, leaving joints ineffective. A weak joint in a HVACR system, or hot and cold water pipes, can damage the entire structural backbone of a building. One pipe burst, or even a continual minor leak, can put an entire facility out of commission and be costly to repair.

Following a few simple tips and tricks of the trade can help any craftsman make a dependable connection for a stronger, more reliable joint.

Recognizing Both Soldering and Brazing

As defined by The American Welding Society, the difference between soldering and brazing is the temperature required to melt the filler metal. Soldering is a joining process that takes place at below 842°F/450°C, and brazing is a similar process that occurs above 842°F/450°C but below the melting point of the base metal.

Both soldering and brazing involve the same basic steps — measuring and cutting, reaming, cleaning, fluxing, assembly and support, heating, applying the filler metal, and cooling and cleaning.

The joining process is also the same for both connections in measuring and cutting, reaming, cleaning, fluxing, and assembly and support. Similarly, these procedures are basically the same for all diameters of tube. In contrast, the variables between the two applications are in the composition of the filler metal, type of flux used, and amount of time and heat necessary to melt the filler metal within an individual joint.

From start to finish, attention to detail in each technique contributes to the strength and overall success of each joint.

Five Guidelines to Follow

1. Make Accurate Measurements

When measuring the length of each tube, accuracy is the key. If the tube is too short, it will not reach all the way into the fitting, creating a weak link. If the tube is too long, it could cock in the fitting and put strain on the system. Both of these conditions could affect the life of the system. In either case, if the tube is not seated in the fitting cup to its full depth, then the integrity of the joint may be compromised.

2. Cut Properly

Once the tube is measured, it can be cut. The cut must be square with the run of the tube to ensure the best fitting. Regardless of the type of equipment used in the cutting procedure, respect for the material must be taken to avoid deformities in the structure of the tube. The tube must then be reamed to remove any burrs.

3. Clean with Care

Although one of the quickest and easiest steps, cleaning is often the most overlooked. Unremoved oxides, surface soils, and oils can inhibit proper flow of the filler metal into the joint causing failure. Cleaning the tube and fitting is critical for the filler metal to flow into the joint and form a strong connection.

When applying the flux, or chemical cleaning agent, it's important to choose one that is not too corrosive and use only the minimum amount of flux needed to make a joint. Careless craftsmanship in applying a flux can be dangerous to the system long after installation.

Fluxes used for soldering are different from those used for brazing; plus, the two types cannot be used interchangeably. Also, the type of flux used can be a good indication of the required temperature of the application.

4. Employ Skilled Assembly Practices

After both the tube and fitting surfaces are fluxed, they should be assembled. A quick way to be sure of even flux application is to slightly twist the pipe within the fitting, making sure the tube is set against the base of the fitting. Furthermore, uniform space around the entire circumference of the joint will ensure a successful joint, while excessive space can cause the filler metal to crack under stress or vibration.

Good practice suggests that after a product has been cleaned, fluxed, and assembled, it should be soldered or brazed within the same period. If left to sit overnight, the joint will need to be disassembled, recleaned, and refluxed before continuing. Protecting the surface that has been cleaned and fluxed and completing the soldering or brazing operation in timely manner ensures clean uncontami-

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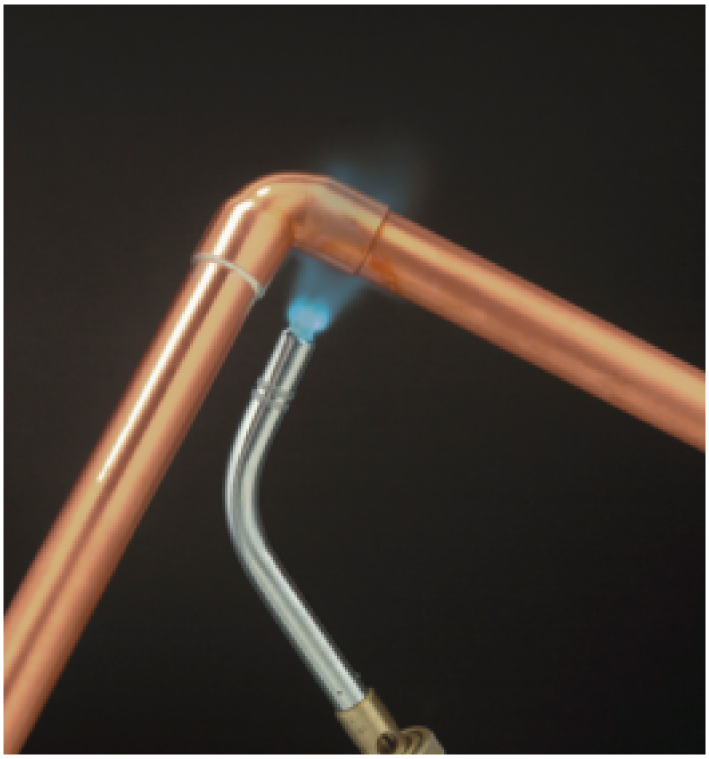
BRAZING & SOLDERING TODAY

Soldering, pictured in use here, is a joining process that takes place at below 842°F/450°C.



Brazing, shown above, generally involves air settling swirl or oxyfuel torches due to higher temperatures used to melt filler metals.

nated surface material that provides an optimum working surface.

It's recommended to preheat the tube, then preheat the fitting. Preheating with the flame ensures a uniform distribution of heat inside and out. When preheating, care should be taken not to overheat the joint.

While similar to soldering, brazing generally involves air settling swirl or oxyfuel torches due to the higher temperatures required to melt the filler metals. First, preheat the tube, then the fitting. When the filler metal starts to flow, it will be drawn into the joint by capillary attraction ensuring a strong, dependable connection.

Similar to preheating, care must be taken not to overheat the joint. Also, cooling should be allowed naturally. Shock cooling with water may cause unnecessary stress on the joint.

Because purging with nitrogen reduces the chance of oxidation at the joints, many HVACR professionals always carry a purging kit with materials such as a nitrogen regulator, charging hoses, blow pipe, and purging and cleaning tips.

Lastly, clean off any flux residue with hot water and/or a wire brush to avoid future corrosion.

5. Work Smart and Safe

Because soldering and brazing require an open oxyfuel or air-fuel flame at high temperatures, care must be taken for the safety of the operator as well as the materials being used. Proper safety training is essential to avoid dangers such as burns, eye damage, fumes, and overexposure to ultraviolet light.

With the use of new technologies and proper protection, the risk of injury associated with metalworking can be greatly reduced. It's important that the user always practice safe operating procedures and wear protective equipment. As an additional word of caution, make certain to read and follow all operation instructions before using any oxyfuel or air-fuel apparatus.

Close attention to detail and strict adherence to all steps will ensure any professional a strong, long-lasting connection for years to come.

New Advances in Soldering and Brazing

As the soldering and brazing industries continue to grow, improved equipment capabilities and efficiency are essential if the plumbing, heating, ventilation, air-conditioning, and refrigeration industries want to keep up with user demands.

Additionally, manufacturers are responding to these needs. TurboTorch®, for example, a manufacturer of air-fuel and oxyfuel torches and accessories, recently expanded offerings with the Viper™ line of brazing alloys, solders, and fluxes. The new alloys, featuring compositions for a range of flow and fill characteristics, are useful for joining copper to copper and are self-fluxing in this application.

Other industry advancements include cadmium-free and lead-free solders that are approved for plumbing and building industries. As more products are engineered for field repair, once difficult tasks now produce quick and consistently durable results.

With manufacturers dedicated to designing and producing better, safer metallurgy equipment, and soldering and brazing professionals crossing new thresholds, today's joints are stronger than ever before.♦

BRAZING & SOLDERING TODAY
TECHNOLOGY NEWS

Lead-Free Solder with Low Susceptibility to Copper Leaching

A lead-free solder, which is significantly less susceptible to copper leaching in a molten state, was developed and tested at Senju Metal Industry Co., Ltd., Tokyo, Japan (Ref. 1). Testing was carried out by dipping coil ends of the copper wire into the liquid solder at 400°C (752°F).

Exemplary compositions of the solder contain the following: 1) copper 8 wt-%, cobalt 1 wt-%, nickel 1 wt-%, and tin in the balance (melting range 228°–409°C, copper leaching rate is 1 μm/s); 2) copper 6 wt-%, cobalt 0.3 wt-%, nickel 0.3 wt-%, gallium 0.07 wt-%, phosphorus 0.02 wt-%, germanium 0.01 wt-%, and tin in the balance (melting range 227°–380°C, copper leaching rate is 1.5 μm/s); 3) copper 2 wt-%, silver 2 wt-%, cobalt 0.2 wt-%, nickel 0.2 wt-%, gallium 0.07 wt-%, phosphorus 0.01 wt-%, and tin in the balance (melting range 218°–281°C, copper leaching rate is 2.2 μm/s). For comparison, the standard Sn-3Ag-0.5 Cu solder exhibits a copper leaching rate of 5.3 μm/s.

Alloying solder with cobalt and nickel decreases the dissolution of copper into the solder melt. Adding P, Ge, and Ga in small amounts inhibit oxidation of the solder at high soldering temperatures.

Wetting of copper coupons with the new solder occurred for 1.5 s of the composition (a), 2.1 s of the composition (b), and 0.5 s of the composition (c), while wetting with the standard Sn-3Ag-0.5 Cu solder occurred in 0.5 s at 400°C.

The low leaching rate prevents a significant reduction of diameter of insulated copper wire or complete disappearance of the wire when the wire diameter is <100 μm.

Thermodynamic Properties of Lead-Free Solders with Ag-Cu-Sn, Ag-Ni-Sn, and Ag-Cu-Ni-Sn Systems

Detailed reference data were calculated and presented in the form of tables in papers (Refs. 2, 3) upon experimental study of solder alloys, as well as the study of phase diagrams made in the Institute of Inorganic Chemistry/Material Chemistry, University of Vienna, Austria.

Enthalpy of mixing of liquid alloys from $Sn_{90}Ag_5Cu_5$ (at.-%) to $Sn_{40}Ag_{10}Cu_{50}$ (at.-%) were measured experimentally as for starting alloys and with Ni additions of 0.05 to 0.3 at.-% with the increment of 0.05%. Also, compositions of liquidus surface of the quaternary Ag-Cu-Ni-Sn system were determined.

Partial and integral enthalpies of mixing of liquid Ag-Cu-Ni-Sn alloys were determined at 1000°C by a drop calorimetric technique using a Calvet type microcalorimeter. They were obtained by adding Ni to the ternary Ag-Cu-Sn alloys with different compositions. The data were evaluated by an extended Redlich-Kister-Muggianu polynomial fit for substitutional solutions. The minimum and maximum in the quaternary system were also calculated. The maximal integral enthalpy of mixing (13310 J/mol at 41 at.-% Ag) occurs in the binary Ag-Ni system while the minimum

integral enthalpy of mixing (–21390 J/mol at 61 at.-% Ni) occurs in the binary Ni-Sn system. Moreover, the experimental data were compared to values calculated by different extrapolation models based on binary data.

Lead-Free Solder Resistant to Tin Whisker Formation and Thermal Shock

The whisker-resistant solder alloy is proposed and tested by Iljin Copper Foil Co., Ltd., Iksan-city, Republic of Korea. The solder contains tin, 0.1–5 wt-% of copper, and 0.001–0.4 wt-% of beryllium (Ref. 4). Also, silver in amount of 1–3 wt-% and boron in amounts of 0.003–0.5 wt-% can be added. For example, the solder compositions are 1) Cu 0.496 wt-%, Be 0.02 wt-%, and Sn in the balance; 2) Cu 0.679 wt-%, Ag 1 wt-%, Be 0.021 wt-%, and Sn in the balance; 3) Cu 2.88 wt-%, Ag 3 wt-%, Be 0.12 wt-%, and Sn in the balance; and 4) Cu 1 wt-%, Be 0.5 wt-%, and Sn in the balance.

The average length of whisker generated on the surface of soldered specimens after thermal shock test was 3–3.4 microns and number of whiskers per unit area was from 3/mm^2 to 5/mm^2, while the standard lead-free solder Sn-3Ag-0.5Cu exhibited whiskers of 11.8–14.4 microns in length at 11/mm^2 to 14/mm^2 whiskers per unit area.

The Be-Cu master alloy is first manufactured when making this solder. Then, tin is melted in a melting pot, and silver with Be-Cu master alloy are added to the Sn melt. The melt is kept in the solder pot for a certain time at 600°–650°C (1112°–1202°F), and the ready solder Sn-Cu-Ag-Be is cast into bar-shaped ingots.

Extruded Rods Comprise a Powder Mixture of Filler Metal and Flux for Brazing Aluminum

A method for manufacturing brazing rods containing both the braze alloy and flux was developed by F.P. Soudage Co., Aubagne, France, for joining aluminum alloy parts in air (Ref. 5). This product comprises a solid, rigid, and compacted material consisting of a powder mixture of the flux 20–30 wt-% and Al-12Si (AWS BAl-4) in the balance. The flux is NOCOLOK® Cs supplied by Solvay, Belgium, that has a melting point of 566°C and contains potassium 29 wt-%, cesium 1.8 wt-%, aluminum 17 wt-%, and fluorine 51 wt-%. Particle size of the flux powder is 10–20 microns. Melting temperature of the brazing rod is 580°C. Also, the composition may comprise the Zn-2Al solder melting at 440°C and the flux containing cesium 51 wt-%, aluminum 10 wt-%, and fluorine 32 wt-%. This flux is melted at 450°–460°C (842°–860°F).

The powder metal-flux mixture is granulated to 3-mm-diameter particles that are dried at 120°–150°C (248°–302°F), and then subjected to hot extrusion at 7000 bars and 450°C for Al-12Si braze rods or 330°C (626°F) for Zn-2Al solder rods. The resulting product is suitable for manual torch brazing or soldering. The patent also describes schematically the devices for granulation and hot extrusion of the composite brazing rods.

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TECHNOLOGY NEWS

New Method for Brazing Steel and Aluminum Sheets Using Spot Welding Equipment

A novel method designed for producing joints between a sheet steel component, in particular, a press-hardened high-strength steel and a sheet aluminum component, is disclosed by Volkswagen AG, Wolfsburg, Germany (Ref. 6). Firstly, a brazing filler metal or a solder deposit is fixed on the steel component by using arc or laser radiation in such a way to keep it secured during transportation. Then, the process applys an electric current and a compressive force using spot welding, pressing the sheet-metal components together, and local heating the region to form the weld or brazed joint between steel and aluminum. Deposition of the brazing filler metal also can be done by induction heating.

The brazing filler metal is selected from Al-, Ni-, or Cu-based alloys or Zn-Al solder. Applications of the solder or copper- or nickel-based braze alloys are preferable because the Al-Si brazing filler metal forms a brittle intermetallic layer at the steel interface. Parameters of the process were not disclosed.

Joining Alumina and Steel by a Laser-Supported Brazing Process

A laser-supported method of joining alumina ceramic with metals was studied by the team of Forschungszentrum Karlsruhe GmbH and Institute of Metalforschung, Eggenstein, Germany (Ref. 7). Pure alumina ceramic and zirconia-toughened alumina (ZTA) (SN80, Ceramtec) were brazed to steels 100Cr6 and Ck45 using a CO_2 laser and the active brazing filler metal CB4 (BrazeTec) in the form of 50 microns foil that contains Ag 70.5 wt-%, Cu 26.5 wt-%, and Ti 3 wt-%. The argon purged with a flow about 300 L/h to prevent oxidation of steel and the braze foil. The laser power was ramped up to 300–360 W. The joining procedure is highly flexible and can be easily adapted to complex component geometries.

Processing time was several minutes, which is significantly less than that of vacuum furnace brazing. The wetting behavior of the brazing alloy was also evaluated, and the contact angle on ceramic was about 30 deg, which exhibits good adhesion to the ceramic. Titanium-rich zones were observed close to ceramic and steel interfaces on scanning electron microscope images, as well as a (Ti, C, Fe) reaction layer at the steel Ck45 interface and a (Ti, Cu, Al, O) reaction layer at the ZTA ceramic interface. Mechanical tests of brazed joints showed that the failure occurred within the ceramic close to the interface between the braze alloy and ceramic part. Thermally induced stresses may lead to cracks in the ceramic, which result in the failure under mechanical loading. The typical bending strength varies between 40 MPa (5.8 ksi) and 80 MPa (11.6 ksi) with a Weibull modulus ranging from 4.3 to 6.1 that is lower than that of the original ceramic. Therefore, the laser process has to be optimized with the focus on reduction of residual thermal stresses in the ceramic.

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Neutron Diffraction Measurement of Residual Stresses in Carbon-Fiber Composite with Copper Alloys for Nuclear Fusion Applications

A high heat flux plasma facing component proposed for the divertor of ITER nuclear fusion reactor is formed by an armor carbon-fiber composite (CFC) NB31 and a heat-sink material (CuCrZr alloy). Residual stresses and strains were experimentally measured in bar specimens of CFC brazed to CuCrZr alloy, as it must withstand cyclic thermal, mechanical, and neutron loads to provide the design lifetime and reliability. The main problem related to CFC-Cu alloy joints is the large thermal expansion mismatch between the two base materials, which generates big residual stresses at the interface during the joining process. A very ductile pure copper layer between the CFC and CuCrZr alloy is aimed to partially relax these residual stresses in the joint.

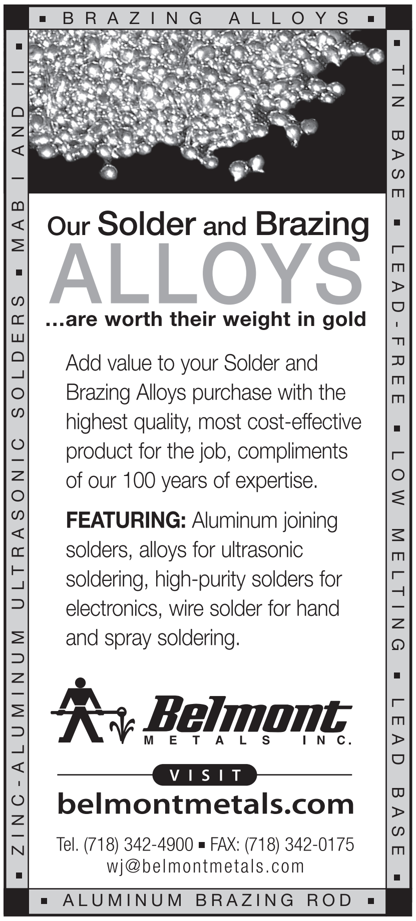
Residual stresses and strains were measured in the joints using neutron diffraction by the team of Universita Politechnica delle Marche and Politecnico di Torino, Italy (Ref. 8). Firstly, the CFC surface was modified by depositing a chromium carbide layer, which provided wetting of the CFC composite by brazing filler metal. Neutron diffraction experiments were performed at the E3 diffractometer of HMI-BENSC, Berlin, having a fixed neutron wavelength 1.37 angstroms. Thermal fatigue cycling was carried out by heating to 450°C followed by fast cooling to room temperature in air using water quenching. The cycles were repeated 50 times for each specimen.

The results for the as-brazed specimens showed expected stress states (tensile in the CFC and compressive in the CuCrZr alloy). The effect of thermal fatigue cycling was a general relaxation of residual stresses, probably due to the formation of microcracks at the CFC-Cu joint during the cycling.

Brazing SiC Ceramic to Graphite Using Ni-51Cr Powder Mixture as a Filler Metal

Recrystallized SiC ceramic was brazed in vacuum to high-strength graphite at 1380°C (2516°F) for 5 min using the brazing filler metal composed of Ni and 51 wt-% Cr powders. The mechanical properties of the brazed joints were investigated in Beijing University of Aeronautics and Astronautics, P. R. China (Ref. 9). The maximum three-point bending strength of the brazed joints was 32.3 MPa (4.7 ksi), which is equal to 81% of the graphite strength.

Microstructure and phase analyses reveal that interdiffusion and chemical reactions took place at the interfaces between base materials and braze alloy, as well as in contacts with the nickel and chromium powders. The braze alloy powder mixture was melted completely. A reaction layer 60–100 microns thick was formed at the SiC surface, and an interlayer 200 microns thick was found between the reaction layer and graphite surface. The reaction layer is mainly composed of Ni$_2$Si, while the interlayer is mainly composed of Cr$_{23}$C$_6$ and Ni$_2$Si phases. At the same time, Si and C dif-

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fused from the ceramic base material into the joint metal.

Low-Cost Joining of Silicon Carbide with a Molten Glass in Air

A method for brazing SiC at 1300°–1600°C in air using calcium aluminosilicate glasses as filler materials was developed in CEA Grenoble, France (Ref. 10), for joining parts of the largest reflector in the world (3.5 m diameter) for the Herschel telescope. This technology has a low cost due to no shielding atmosphere and facilitates repairing damaged ceramic components. Many glass-ceramics were studied earlier to join SiC and SiC_f/SiC composites in vacuum, but only a few of them exhibited wetting and interfacial reactions with ceramic. The SiC substrate used in these tests comprised 2 wt-% of B4C as a sintering aid. Wetting of calcium aluminosilicate glass on SiC was studied using the sessile drop technique in air in the temperature range 1100°–1590°C. Good wetting was observed at the temperature above

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1300°C, as well as good filling of the joint gap by the glass containing 23CaO-15Al_2O_3-62SiO_2 (wt-%).

Lowest contact angle of the glass on the SiC substrate was found as little as ~20 deg at 1400°–1500°C and holding time more than 3 min. Average shear strength of SiC joints at RT was 42 MPa. These results clearly showed that SiC/(23CaO-15Al_2O_3-62SiO_2) is a reactive system, despite no reaction layer was observed at the interface. Reactivity is enhanced by oxygen from air that forms bubbles in the liquid glass. The wetting of SiC ceramic occurs by dissolution of the silica layer in the molten glass at the liquid-solid-vapor phase equilibrium. Further work is planned to study the formation of crystals at the edge of the joint.

Testing of New Filler Metals for Reactive Air Brazing Ceramic-to-Ceramic for Fuel Cell Applications

Reactive air brazing (RAB) is a promising method to join metals to ceramics in air using brazing filler metal modified with copper or silver oxides. A number of new compositions of oxide-modified filler metals were studied and characterized in Aachen University (Ref. 11) and Fraunhofer Institute fuer Keramische Technologien und Systems, Dresden, Germany (Ref. 12).

The following brazing filler metals were tested for joining alumina in air at 970°, 1050°, 1150°, and 1350°C for 20 min: Ag8Cu, Ag8Cu0.5Ti, Ag8Ni, Ag0.5Al, Ag4Cu4Mn, and Ag4Cu4Ni. The contact angle of all these braze alloys on alumina was in the range of 30–40 deg at all the above mentioned brazing temperatures except the Ag8Ni alloy at 1350°C that is about 90 deg. The tensile strength of brazed joints depends on the brazing temperature — the brazing filler metal Ag8Cu showed strength more than 100 MPa after brazing at 1050°C, while only about 60 MPa after brazing at 1150°C, and 40 MPa after brazing at 970°C. The filler metal Ag8Cu0.5Ti provided tensile strength of brazed joints more than 80 MPa after brazing at 1150°C, while only about 60 MPa after brazing at 1050°C, and only 30 MPa after brazing at 970°C. The brazing filler metal Ag4Cu4Ni showed the best result more than 60 MPa after brazing at 1350°C. All other filler metals had lower strength of brazed joints of alumina.

Thermal analysis clearly provided evidences of metal-oxide reactions during brazing resulted in the formation CuO and NiO oxides and their interaction with alumina.

Formation of interfacial layers — controlled by thermal treatment — between RAB braze metal and the base metal Crofer 22AP (Fe-22.7Cr-0.4Mn) was investigated at different amounts of CuO (from 0 to 10.5 mol-%) added to silver (Ref. 12). Thermal treatment was changed by using induction or furnace heating for brazing at 1000°C followed by annealing at 850°C for 200, 500, and 800 h. The induction brazing process led to the formation of thin interfacial layers both at the interface with the ceramic 3YSZ and the base metal. Ceramic samples brazed with Mn-containing base metal had thicker oxide layers at the metal interface than at the ceramic interface, independently on the CuO content in silver paste. The growth of the layers is controlled by diffusion of minor elements originating from the steel Crofer 22AP. Tailoring of the braze composition by varying the content of CuO does not have a significant effect on the microstructure of the interfacial layers.

Joining of Vanadium-Modified Diamond to (Kovar) Fe-42Ni Alloy Using the Zn-5Al Solder

A low-temperature process for joining ornamental diamonds to metal polishing jigs was developed and investigated in Tokai University, Tokyo, Japan (Ref. 13). The process includes brief metallization at 1080 K without compromising the diamond clarity. Reactive vanadium hydride powder was used for low-temperature vacuum metallization of the diamond surface that was covered by dot-like islands of vanadium. The metallization process was performed using Ag-Cu eutectic powder and vanadium hydride powder at the weight ratio of 1:4.5. After the formation V_4C_3 at 1080 K for 240 s, silver dots were deposited also by maintaining temperature to melt the Ag-Cu eutectic. Soldering with the Zn-5Al filler metal was carried out in air using ultrasonic vibration.

Thermogravimetric and differential thermal analysis of the vanadium hydride-diamond system were performed in argon to find out what vanadium carbide phases are formed in the contact. The formation of vanadium carbides on the diamond surface is a continuous exothermic reaction. The DTA test showed three reactions at 608, 710, and 780 K. The diamond weight began decreasing with the formation of V_2C phase and continued decreasing during the formation of V_4C_x. As the result $V_4C_{2.67}$, V_4C_3, and V_8C_7 carbides were found.

The average strength of the joints was 20 MPa. Joint strength does not depend on the number of the surface modification cycles, whereas the wetting behavior of the solder was improved. It was also found that the Al_4C_3 reaction product was formed during the ultrasound soldering process at 770 K.

Low-Oxygen, Controlled Atmosphere Oxynon® Furnace for Brazing Stainless Steel Heat Exchangers and Metal-Ceramic Joints

The drawback of continuous furnaces for controlled atmosphere brazing (CAB) is the application of explosive gases such as hydrogen. A nonoxidizing continuous furnace using only inert gas atmosphere was newly developed by Kanto Yakin Kogyo Co., Kanagawa, Japan, for brazing stainless steel heat exchangers at 1443 K with BNi-5 filler metal (Ref. 14). The furnace has a carbon/carbon composite conveyor belt that can be used up to 2873 K. The Oxynon® furnace employs a principle that is completely different from hydrogen and carbon monoxide reduction. The partial oxygen pressure is low in the furnace atmosphere (less than 10^{-15} Pa) due to the formation of CO by reacting of carbon-based conveyor with residual oxygen contained in the inert gas atmosphere. The thermodynamics and chemistry of this principle are described in the paper with details. The furnace was used for brazing SUS316 small heat exchangers, as well as large heat exchangers with the dimensions 600 × 1000 × 110 mm, weighing ~230 kg.

Also, the same atmosphere can be used for brazing stainless steel SUS304 or Kovar to alumina ceramic. Both Ag-Cu filler metal and active Ag-Cu-Ti filler metal showed good wetting of ceramic in the oxynon furnace, and ultrasonic tests confirmed the formation of dense brazed joints.

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11. Bobzin, K., Schläfer, T., and Kopp, N. New filler metals with improved contouring accuracy for brazing ceramics, v. 263, 64–69.

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