Industrial Surface Solutions

Soldering and Brazing of Metals, Lightweight Metals, Ceramics, Glasses and Composites
-Introduction, Fundamentals and Applications-

4th Conference on Thermoelectrics
December 10 – 12, 2014

Dr.-Ing. Ino J. Rass
EUROMAT® GmbH -Industrial Surface Solutions-
Hermann-Hollerith-Strasse 6
D-52499 Baesweiler b. Aachen
www.euromat.de
Contents of Presentation

- Introduction
- Historical view of soldering and brazing
- Definitions
- Engineering of soldering and brazing solutions
- High temperature brazed heat exchangers and applications
- Introduction to ultrasonic-soldering technology
- Low temperature ultrasonic-soldered heat exchangers and applications
- Conclusion
Introduction EUROMAT® GmbH -Industrial Surface Solutions-
Founded 2006 in Aachen – Solutions made by Glueing, Soldering, Brazing, Coating and Heat Treatment

Engineering
- Optimizing of the function of parts and tools enabled by new materials and coatings as well as glueing/bonding/brazing technologies

Service
- ForMat®: Thin Film Technology for wear resistant and low friction coatings
- BodyClad®: Sintered Ceramic-Metal-Coatings and Parts for Protection against Wear and Corrosion
- S-Bond®: Ultrasonic-Soldering of Metals, Light metals, Glass, Ceramics and Composite Materials -Leadfree and fluxless-
- NanoPlas®: Polymer and Nano-Coatings for No-Wetting, Wear and Corrosion Protection

Products
- Powders, Tapes, Preforms, Polymer, Sol-Gele, Cooling Plates, Wear Parts and Plates, Targets
  Ultrasonic Solders, Ultrasonic Equipments und Heating Systems
Historical View of Brazing
EVALUATED DATAS (SOURCE DVS 2010: BRAZING - AN INTRODUCTION)

- 4000  Mesopotamia: Soldering of jewelries and goods using gold and silver.
- 3800  Egypt: Soldering of jewelries and goods using gold and silver.
- 1600  Europe: Soldering of tools and jewelries made out of bronze.
- 120   Rome: Soldering of weapons and chain mails with copper solders using fluxes like borax and soda.
- 700   Europe: Using different kind of solders for professional service.
- 800   Europe: Using solder alloys like AgCu and AuCu.
- 1200  Europe: The peak of goldsmith’s-arts. Production of weapons drove soldering.
- 1600  Europe: Use of CuSn and Ag-based solders for soldering of Fe-based materials.
- 1800  Europe: Soldering of copper steam vessels. Begin of scientific evaluations.
- 1900  Europe: Welding is established beneath soldering. First use of Al-solder.
         Use of Cd to reduce solder temperatures.
- 1930  Soldering and brazing for large-scale production in electronics.
- 1950  Using low melting Ag-solders for industrial applications and handcraft.
         Soldering/Brazing of new materials, glass, ceramics, composites.
- 2000  Development of nano solder materials. Using lead-free-solders (RoHS), Intermetallics etc.
Historical View of Brazing

Evaluated Applications (Source DVS 2010: Brazing - An Introduction and Presentation* Dr. Rass at Materials Science Institute – RWTH Aachen 1996)

- Etruscan Gold Pontic with Calve Teeth (400 B.C.)*
- Crown of an Egyptian Princess Gold-Laspis Lazuli-Turkey Stone Several Soldering Steps (1860 B.C.)
- Gold Bowl with solder loops Found in Iraq (2600 B.C.)
- Etruscan Gold Bowl made out of 137,000 Single Gold Pellets (600 B.C.)
- Rotating Table Soldering Machine for Continuously Soldering of long Parts using Gas
- Robotic System for Soldering of Cu-Tubes of Heat Exchanger Using Inductive Heating
- Belt Furnace with Protection Air Gas Atmosphere
Definitions

Joining Technologies

- Non Permanent
  - Form Positive Bonds
- Permanent
  - Substance-to-Substance Bonds
    - Welding
    - Glueing
    - Soldering
  - Non-Positive Bonds

Example Rail Bolts and Nails

Example Vacuum brazed St-TiAl
Source: Material Science Institute Aachen

Example:
1.040 °C, 45 min
Braze Material Ni102
Definitions

Soldering/Brazing (ISO 857-2)
Joining processes in which a molten filler material is used that has a lower liquidus temperature than the solidus temperature of the parent material(s), which wets the surfaces of the heated parent material(s) and which, during or after heating, is drawn into (or, if pre-placed, is retained in) the narrow gap between the components being joined.

Note 1 to entry: These processes are generally carried out with metals but they can also be carried out with non-metallic materials. The filler material always has a different chemical composition from the components being joined.

Note 2 to entry: If the process is carried out without capillary attraction, it is often described as braze welding.

Soldering
Joining process using filler metal with a liquidus temperature of 450 °C or less

Brazing
Joining process using filler metal with a liquidus temperature above 450 °C

Coating
Deposition of a layer or layers of material on a surface to obtain desired properties and/or dimensions
Definitions

Temperatures

- **Soldering**
  \[ T_{\text{liq.}} < 450 \, ^\circ\text{C}; \text{Flux/no Flux} \]
  Atmospheric Conditions

- **Brazing**
  \[ T_{\text{liq.}} > 450 \, ^\circ\text{C}; \text{Flux/no Flux}; \]
  Vacuum; Protection Air Gas

- **High Temperature Brazing**
  \[ T_{\text{liq.}} > 900 \, ^\circ\text{C}; \text{no Flux}; \]
  Vacuum; Protection Air Gas

Materials for Soldering and Brazing

- **Soldering**
  Bi, In, Sn, Zn (R.E.)

- **Brazing**
  Mg, Al, Cu, Ni, Ag, Au (Ti, In)

- **High Temperature Brazing**
  Fe, Ni, Ag, Cu, Au, Pt, Pd
Engineering of Soldering and Brazing Solutions

1. Solderability/Brazeability
   - Ability (Material)
   - Reliability (Construction)
   - Possibility (Production)

2. Wettability
   - Temperature below melting temperatures of base materials
   - Penetration of solder/braze material into the gap
   - Metallurgical reaction between base materials and molten solder/braze material
   - Solidification of the liquid phases in the gap

3. Surface Activation
   - Activation by fluxes (temperature, application, corrosion, cleaning, safety)
   - Activation by shielded gas (temperature, easy application, corrosion, cleaning)
   - Activation by vacuum (temperature, pressure,

4. Flowability of Liquid Solder/Braze Material
   - Gap size (adhesion-cohesion, reaction, crystallisation)
   - Solder/braze material (0.05-0.5 mm: e.g. Au 0.1 mm, Ni 0.15 mm, Ag 0.05-0.3 mm, Al 0.05-0.25 mm)
   - Metallurgical reactions (change of chemical composition)

5. Metallurgical Processes
   - Solution of base material into liquid solder/braze material
   - Dynamic balance between liquid and solid phases – Crystallisation
   - Diffusion in solid phase

Source: IOT RWTH Aachen
Engineering of Soldering and Brazing Solutions

6. Design for Soldering and Brazing
   • Process Conditions (loads, temperatures, surroundings, etc.)
   • Base materials (heat treatments, surface conditions, physical properties, etc.)
   • Evaluation (solder/braze material, process, fixing, joints, constructions)

7. Base Materials
   • Metallic or non-metallic (wetting, thermal loads, thermal extension, mismatch)
   • Combinations (thermal mismatch, tensions)

8. Solder/Braze Materials
   • Evaluation (Sn-, Ag-, Au-, Cu-, Ni-, Pd-, Pt-base: depending on base materials, temperatures)
   • Application (foil, paste, spraying, plating)
   • Flux/noFlux (process, temperature, braze/solder material, application, cleaning)

9. Soldering/Brazing Process
   • Application (temperatures, gaps, heating sources, surface activation, solder/braze material amounts, quality)
   • Evaluation (vacuum/shielded gas, diffusion, induction, flame, plasma, resistant, arc)

10. Quality Control
    • Destructive/non destructive
    • Simulation

11. Health and Safety

Norms and Standards

- DIN ISO 857-2: Definitions
- DIN EN 1044: Brazing-Additionals
- DIN EN 1045: Brazing-Fluxes
- EN 14324: Brazing: Working instructions
- DIN EN 12797: Brazing-Destructive testing
- DIN EN 12799: Brazing-Non-destructive testing
- DIN EN ISO 18279: Brazing-Irregulares
Brazing Application Heat Exchanger

- Part: Heat Exchanger for Sterling-Engine in Block Heat and Power Plant
- Material: Austenitic CrNi-Steel
- Requirement: Gap free and He-density
- Braze Material: Ni-Base / 1050°C

⇒ Realization only by Brazing Technology
  ➢ 900 Joints in one Process Step
  ➢ High Reproducibility
  ➢ High Reliability

Source: Listemann Technology AG - Liechtenstein
Application Heat Exchanger Turbines

- Part: Heat Exchanger in Gas Turbine
- Material: Ni-based Alloys
- Anforderung: Gastight, Fatigue Resistance, Temperature Stability
- Braze Material: Ni-Base modified / 1000-1080°C

MTU Aero Engines

Wafer Structure

⇒ Realization only by Brazing Technology
  ➢ 14,000 Joints in one Process Step
  ➢ Temperature Stability
  ➢ Low Deformation

Source: Listemann Technology AG - Liechtenstein
Application Thermal Management Complex Molds

Advantages
- Unlimited Design of Cooling Channels
- Easy to Machine
- Large Area Brazing
- Dense Joints
- Integration of Heat Treatment

Vacuum Brazing
New Cooling Concepts by 3D-Laser Printing and Brazing

Information
- Mold Core 3D Laser Printed. Material 1.2709.
- Integrated Process of Heat Treatment
- Individual Cooling Design

Source: LBC Engineering - Germany
Application SOFC Fuel Cells for Electro Mobility

Source: Stephan Zügner, Dissertation 2009
**Application Turbine Technology**

- **Turbine V2500 (e.g. Airbus A320)**
- MCrAIY / CBN, brazed on tip of turbine blade
  - Dense gaps
  - Reduction of emissions and fuel consumption
  - Low wear

Source: MTU München GmbH
Application Exhausting and Cooler Systems

Reduction of Emissions
- Exhaust Catalysts
- SCR-Technology
- EGR-Cooler
Ultrasonic Soldering Technology (<450 °C)

Properties

- Fluxless processing at air regarding RoHS-Rules using lead-free solder materials
- Creates strong, thermally conductive joints at relatively low temperatures
  - Joining temperatures 140 °C to 450 °C depending on used solder materials
  - Improvement over conductive adhesives
  - Higher joining temperatures than most solders (In-based)
- Allows joining of dissimilar materials/CTE
  - Metals and Light Metals
  - MMC, Ceramic/Carbides/Carbon, Glass, Composites Al-SiC/SiSiC
- Process can be automated
  - Able to get economies of scale in high volume applications
Application Focus Ultrasonic Soldering Technology

- Heat Exchangers and Cooling Plates
- Metallization of Light Metals, Ceramics, Composites, Glass
- Composites Materials (e.g. Al:SiC, Al:Al₂O₃, Si:SiC)
- Lightweight Structures / Aluminum tools & molds
- Foams and Porous Materials
- Target Materials
- Solar cells
Mechanical Activation - Principals

- No Wetting
- Fluxless

- Wetting
- Fluxless

- Brushing / Peening

- Ultrasonic Agitation +/- Pressure
Ultrasonic Activation – Principals using Ultrasonic Horn

- A Solder iron tip
- B Solder
- C Flux
- D Oxide layers
- E Wetted/Bonded
- F Base material

**Soldering w/ flux**

**No Flux Soldering**
# Ultrasonic Solder Materials from 140 °C up to 440 °C

Base Sn and Zn alloyed with Ti, Ag, Bi, Sb, In, Mg, Al, Cu + R.E.

## Evaluated Solder Materials 220-1 (SnAgTi+R.E.) and 400-2 (ZnAgAl+R.E.)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SBond® 220</strong></td>
<td>221</td>
<td>232</td>
<td>250-280</td>
<td>7,42</td>
<td>17,7</td>
<td>1,6-1,7</td>
<td>48</td>
<td>220</td>
</tr>
<tr>
<td>SnAgTi+R.E.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>221</td>
<td>230</td>
<td></td>
<td>7,38</td>
<td>27,9</td>
<td>1,3</td>
<td>57</td>
<td>-</td>
</tr>
<tr>
<td>SnAg 3,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SBond® 400</strong></td>
<td>388</td>
<td>401</td>
<td>400-420</td>
<td>7,14</td>
<td>26,6</td>
<td>1,4-1,7</td>
<td>72</td>
<td>-</td>
</tr>
<tr>
<td>ZnAlTi+R.E.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>388</td>
<td>400</td>
<td></td>
<td>6,92</td>
<td>27,7</td>
<td>0,69</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>ZnAl4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SBond® 220 Joint Sealing Capabilities**
- Covar to Al: 3,8x10⁹ atmospheres/cc sec
- SiC to Invar: 5x10⁻¹⁰ mbar*L/sec (helium leak rate)
- Glass to Metal: 4,1x10⁹ atmospheres/cc sec

**SBond® 220 Corrosion capabilities**
- Good atmospheric protection/salt spray resistance is good since Ti passivitates alloy
- Resistance to Cl in solution
- Other corrosion data, updates or specials on request

*) Dynamic
Joint Structures - $T_{\text{solder}}$ 260 °C

Ultrasonic Soldering Technology

- Joins nearly all metals
- Offer dissimilar material joints
- CTE mismatch strains lowered
Joint Structures of Al-Al$_2$O$_3$ (MMC) - $T_{\text{solder}}$ 260 °C

Ultrasonic Soldering Technology
Joint Structures of Silicate Glasses - $T_{\text{solder}}$ 260 °C

Ultrasonic Soldering Technology
Joint Structures of Steel to Al$_2$O$_3$ - $T_{solder}$ 260 °C
Ultrasonic Soldering Technology
Joint Structures of Al-Al and Ti-Ti - $T_{\text{solder}}$ 440 °C

Ultrasonic Soldering Technology

- Higher temperature capability
- More base materials interaction
- Stronger bonds than Sn-based
- 2x thermal conductivity of Sn-based
Joint Structures of Porous Materials - $T_{\text{solder}}$ 260/440 °C

Ultrasonic Soldering Technology

220 Sn-based Active Solder
Stainless (P/M) Filter
Preforms Bonded to Copper

400 Zn-based Active Solder
Stainless (P/M) Filter
Preforms Bonded to Copper
Applications - $T_{\text{solder}}$ 260 °C

Ultrasonic Soldering Technology

- MMC tie rods for pistons
- Al:SiC Heat spreaders
- Glass windows / instruments
- Al-foam / ceramic armor tile
- Al:SiC joint
- Zirconia / steel
Applications Target Bonding- $T_{\text{solder}}$ 260 °C
Ultrasonic Soldering Technology

Ceramic to copper
Tungsten to copper
Ti-Boride to copper

Chromium to copper backing plate
Invar to copper backing plate
Applications Heat Exchangers - $T_{\text{solder}} = 260 \, ^\circ\text{C}$

Ultrasonic Soldering Technology

- Aluminum Fin-Plate
- IC Processor Coolers
- Graphite foam-Al case
- Al-Cu tubing & joints
- Al-tube to Al-plate
- Cooling plates – Stainless steel to copper
- Power Electronics Al-Cu Foam joints
- Innovative coolers - Al-foam to Cu and AL
Applications Heat Exchangers - $T_{\text{solder}}$ 260 $^\circ$C

Ultrasonic Soldering Technology

- Aluminum to Graphite Foams
- Aluminum-Copper Chip Package Base
- Al:SiC Active Cooled Electronic thermal base plate
- Aluminum Fins on Al
SnAgTi+R.E. 220-1. Thermal Management

Cooled Al: SiC electronic package heat sink

SiC to Aluminum Heat Sink

Aluminum Finned Heat Sink

Graphite Foam to Aluminum Radiator
Applications Heat Exchangers - $T_{solder}$ 260 °C

Ultrasonic Soldering Technology

Electronics / Optical Components

- Substrate (Cu-AlN-Cu)
- Die / Silicon or GaAs
- Bonding Alloy
- Base Plate
- Active solder
- Gr-Foam

- Gr-foam onto Alumina
- Storage Disks
- IC Die attachments
- Power electronics cooling
- Power IC attachments
Ultrasonic Metallization and Nano-Reaktive-Soldering
Fluxless and Lead-free Soldering at Atmosphere

Testing of Bond Strength

Fluxless ans Lead-free Soldered PbTe-Thermo Couple onto Cu
Conclusion

• Soldering and brazing becomes more and more interest in production technologies and development of new products.
• Joining of new materials are only possible by using soldering and brazing technologies.
• Engineering of soldering and brazing solutions are the key for innovative and successful products.

Development Activities

• Soldering and brazing of dissimilar materials like steel to glass, aluminum to ceramics, crystals to composites.
• High demands to strength and thermal conductivities as well as corrosion resistance even at high temperatures.
• Light weight structures and metallization.
• Simulation and non-destructive testing.
• Nanosized soldering and brazing materials to reduce joining temperatures.
Thank you very much for your attention