Development of Electromagnetic Pulse Welding Technique for DMW

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Outline of the Presentation

1. Introduction
2. Electromagnetic Pulse Welding Principle
3. Experimental set up & Results
4. Numerical Simulation of DMW
5. Challenges
6. Conclusions
7. Future Plan
8. References
Nomenclature

Electro Magnetic Welding (EMW)
Electro Magnetic Pulse Welding (EMPW)
Magnetic Pulse Welding (MPW)
Magnetic Pressure Welding (MPW)
Magnetic Impulse Welding (MIW)
Electromagnetic Pulse Technology (EMPT)
Electromagnetic Pulse Metal Processing Techniques (EPMPT)
Conventional welding processes show difficulties in joining dissimilar metal combinations due to difference in M.P.

In contrast; EMP welding technology allow welding between dissimilar metal by plastic deformation without melting of base metal.

The metallurgical bond is produced without fusion; mechanical and chemical properties of materials do not under go liquid–solid transformation.

Produced joint does not adversely affect the heat treatment and microstructure of metal, so the procedure does not require preliminary and post-weld heat treatment.

EMW is a solid state welding; that produces a weld by high velocity impact.

EMW are more competitive than conventional methods in terms of Simplicity, environmental friendly and automation.
Principle of EMP Welding Technology

Equivalent Circuit

Cross Section of Graphic depicting the Tool Coil and Work piece
Schematic of MPW Process of two tubes
(Source: MPW, Manual, LISBOA-2010)
EM Technology: Potential Applications across Various Sectors

Automobile Sector
Electrical Industry:
    Crimping ..
Ship Building Industry
Aluminum Fabrications in
    any Industry
Dissimilar Materials
Advance Core and
    Cladding Steel
Experimental Setup (40kJ, 20kV)

EM Tool (6 Disc Coil with Field Shaper)

EM Forming /Welding System

Schematic Block Diagram

4 Disc Coil without Field Shaper
4 Disc Coil and Field Shaper For D9/T91 Tube to SS304 Plug Weld Trial
Weld Analysis of D9/T91 tube to SS304 plug

Indicative sample of D9/T91 steel to SS304 EMW sample.

Micrograph of welded sample

gunta sample

Polished and etched with Oxalic acid
Burst Test of EM Welded Sample

- EM welded D9 clad to SS304 end plug, tube ruptured at TIG welded joint @110MPa

- EM welded joint is also stronger than TIG welded joint, this could be due to heated affected zone.

- This proves the superiority of solid state high strain welding.

The Sample was subjected to hydraulic pressure test using Maximator make, German test Equipment (Capacity: 400Mpa)
EM Pulse Welding of Copper tube to Soft Iron

Joining of soft iron to copper proves to be very beneficial for several industrial applications. Conventional fusion welding method, by applying the thermal energy to melt these two metals and fuse together leads to unreliable weld due to vast difference in melting points. It is difficult to remove oxide layer on Al. Alloying of the two metals creates a brittle inter-metallic compound that is mechanically and electrically poor in quality.

<table>
<thead>
<tr>
<th>Dimension (AL tube)</th>
<th>Measure (mm)</th>
<th>Dimension (Cu Disc)</th>
<th>Measure (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD</td>
<td>48</td>
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<tr>
<td>Thickness</td>
<td>2</td>
<td>Stand off</td>
<td>2</td>
</tr>
<tr>
<td>Weld length</td>
<td>20</td>
<td>Weld length</td>
<td>20</td>
</tr>
</tbody>
</table>

Geometry and Dimensions

Current waveform

Pressure on Copper tube

4 Disc EM coil

300 MPa

85 us
Test Results of Cu tube to Soft Iron weld

Samples of copper tube and soft iron

Optical Micrograph of interface

Pull out test

Helium Leak test

Interface penetration of copper and iron using XRD
Experimental Setup for Flat Sheet Welding

Source: APPD, BARC, Bombay & Dr. Sachin D. Kore, IIT Guwahati

![Diagram of welding setup with labels: SPARK GAP, LOAD COILS, CAPACITOR, Upper Coil, Lower Coil, Plate, COIL, FIXTURE. Diagrams illustrate the flow of flux and plate velocity.]

- SPARK GAP
- LOAD COILS
- CAPACITOR
- Upper Coil
- Lower Coil
- Plate
- COIL
- FIXTURE
EM Welded Samples Test Results

Al to Al-Li

Al to AZ 31

Al to SS

Cu to SS
Numerical Simulation Test Results

Simulations were performed at various applied voltages, 1 kV to 9 kV. There is an increase in the depth of deformation with the increase in applied voltage. Work piece was not getting full deformation at 5kV. This may be due to non-uniform distribution of magnetic field and increased stiffness of the work piece. Depth of forming was increasing from 35 mm at 5kV to 44.7 mm at 8kV. At 9kV, the depth of deformation decreases, this is due to the rebounding effect.
Depth of deformation Vs applied voltage
Challenges involved

Electrically Failed direct coil  MSE in Be-Cu FS  MSE & Failure in direct coil

• Mechanical & Elect properties change with increase in temperature.
• Increase in tempt. Magnifies the joule heating effects.
• Magnetic Saw effect (MSE) is due to molten metal pushed away by magnetic field, resulting in the damaged surface of the FS with saw like marks.
Be-Cu Field Shaper with replaceable Copper Insert after trial
Methods to Reduce Magnetic Saw Effect (MSE)

- Use of material with high melting point like Tungsten/ Tantalum etc.
- Use of a coil of higher inner radius compared to skin depth.
- Complete elimination of irregularities or pre-existing cut in the inner surface of the coil.
- Use of liquid N\textsubscript{2} for cooling to reduce the MSE.
- Use of a Multilayer or Spiral coil to reduce the characteristic surface temperature.
- To overcome MSE, high field zone is to be replaced by disposable Inserts viz Tantalum, Copper Tungsten, Niobium, AISI316 steel, P91, AA2014 and ETP copper. Among these Copper showed most promising results in terms of the quality of the joint.
Conclusion

- EM Pulse Welding of Dissimilar Metal have been demonstrated for various combinations and sizes of metals.
- Optical Micrograph and SEM showed good metallurgical bonding.
- High strength Disc coil and field shapers have been developed.
- At high field (~40T), magnetic sawing effect/deformation are seen on Field shaper.
- Disposable field shaper at higher (>45) pulse field may be deployed.
- In case of Flat sheet; at higher voltage, the depth of deformation decreases due to rebounding effect.
Future Plan

Analysis of Failure mechanism of tool coil and mitigation technique

Simulation of EMW interface under high strain rate for Dissimilar Metals

Optimisation of electrical and mechanical parameters for DMW

Inspection and Repair of EMW to be devised

EM pulse welding seems to be a potential technique for DMW for high strength steels such as ODS steel (generation IV cladding Material) retaining its metallurgical characteristics

Testing of EMW samples in reactor environment


THANK YOU