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Solid state welding of dissimilar materials

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Solid State Welding
of Dissimilar Materials

Pedro Vilaça @ Aalto University, Finland

THE NORDIC WELDING
CONFERENCE
23 August 2018

Solid State Welding
…Prior to all Fusion Welding Techniques

Solid State Welding
…Forging Leading the Way

Solid State Welding
Leading the Way and… Providing High-Value Modern Solutions

Agenda

- Overview of Solid State Welding Techniques
- Overview of Friction Based Techniques
- Friction Stir Welding
  - Fundaments and standardization
  - Examples of industrial applications
  - Characterization of dissimilar joining: Steel/Al and Al/Cu
- Overview of Friction Stir Welding Variants
- Overview of Friction Stir Based Variants
  - Joining aluminium to polymeric based components
Overview of Solid State Welding Techniques

- Diffusion Welding
- Ultrasonic Welding
- Explosion Welding/Cladding
- Friction Based Technology

High Frequency Welding
Flash Welding
Stud Welding

Viscoplastic or "third-body" domain

Solid State Welding and Processing Technologies

✓ Overview of Friction Based Technology

Overview of Friction Based Technology

...Viscoplastic or "Third-body" Domain

Friction Extrusion
Friction Hydro Pillar
Friction Riveting

Overview of Friction Based Technology

...Viscoplastic or "Third-body" Domain

Friction Rotary Welding
Friction Linear Welding
Friction Flow Drilling

Overview of Friction Based Technology

...Viscoplastic or "Third-body" Domain

Friction Surfacing
Production of Functionally Graded Materials (FGM)

Overview of Friction Based Technology

...Viscoplastic or "Third-body" Domain

Friction Flash to Tube (F2T) – Aaltube @ Aalto

IPR: Aalto University, FI 20160043; 2/02/2016
Overview of Friction Stir Welding

Features of Industrial Relevance: Patent and Fundamentals

- One of the most significant developments in welding technology in recent history
- Last patent (US 5,813582) assigned to TWI expired on 29 September 2015

Friction Stir Welding
Features of Industrial Relevance: Standardization

ISO 17536:2018 Friction Stir Welding—Aluminium

- Part 1: Introduction
- Part 2: Design of weld joints
- Part 3: Qualification of welding operations
- Part 4: Specification and qualification of welding procedures
- Part 5: Quality and inspection requirements

Friction Stir Welding
Features of Industrial Relevance: Application Samples

Audí R8 Le Mans

Prompeo @ Finland

Cruise Naval livery

FMSW of metal on metal: Transports, transmission systems

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FMSW of metal on metal: Transports, transmission systems
Friction Stir Welding
Features of Industrial Relevance: Application Samples

New FSW for Space launch System: IF - Vertical Assembly Center (VAC) (NASA) Michoud Assembly Facility New Orleans

Courtesy by: ESAB

Electrical Transformers Bobbin's (Siemens, Portugal)

Courtesy by: RIFTEC (HAI Group)

Nuclear Fuel and Waste Management
Cu - OFP Penetration 

Friction Stir Welding of Dissimilar Materials
Joining Aluminium Alloy to Steel Sheet

Motivation
All car manufacturers strive for a solution

The ultimate solution to optimized BIW and chassis... with many other applications


Friction Stir Welding of Dissimilar Materials
Joining Aluminium Alloy to Steel Sheet

The Innovative Joint Concept
Promote Joining Mechanism

Innovative lap joint

Conventional FSW lap joint

Clenching

Joining in one step
Friction Stir Welding of Dissimilar Materials
Joining Aluminium Alloy to Steel Sheet

Analysis of Results
Multipass WPS – Optical Microscopy

Friction Stir Welding of Dissimilar Materials
Joining Aluminium Alloy to Steel Sheet

Electrical conduction along the crossing through the continuous Ni base on the joint interface

Friction Stir Welding of Dissimilar Materials
Joining Aluminium Alloy to Steel Sheet

BUSBAR CASE-STUDY: COIL

Friction Stir Welding of Dissimilar Materials
Joining Aluminium to Copper

Clamping force relaxation test:
% AAM101-T4: 90% ACS (unaffected hypereutectic, with laps compressed to thickness = 0.5mm)
% CuOF: 0% (unaffected hypereutectic, with laps compressed to thickness = 0.5mm)

Friction Stir Welding of Dissimilar Materials
Joining Aluminium to Copper

FSW weldability analysis:
% Coil body A1050-H1450: 35% ACS (unaffected hypereutectic, with laps compressed to thickness = 0.5mm)
% Coil clamping CuOF: 0% ACS (unaffected hypereutectic, with laps compressed to thickness = 0.5mm)

Why to use Bimetallic Aluminium Copper Busbar?
Replacing the connection ends of aluminium busbar with copper:
- To reduce the electrical contact resistance at the bolted clamped points
- To promote electrochemical similarity
- To increase the mechanical resistance at higher temperatures
- To reduces bolt re-tightening maintenance

FSW allows efficient joining of Al-Cu needed for high series of high quality busbar products?
Friction Stir Welding of Dissimilar Materials
Joining Aluminium to Copper

FSW DOE optimized joint

Friction Stir Welding of Dissimilar Materials
Joining Aluminium to Copper

Temperature monitoring

Electrical properties
- Electrical resistance between mild steel base materials while under a clamping force from a vice was measured for comparison using three different forces:
  - Low - samples would stay together but could easily be moved by hand
  - Medium - samples could not be moved by hand
  - High - vice tightened as much as possible

<table>
<thead>
<tr>
<th>Force</th>
<th>Contact resistance (μΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>300 x 500</td>
</tr>
<tr>
<td>Medium</td>
<td>340 x 30</td>
</tr>
<tr>
<td>High</td>
<td>110 x 30</td>
</tr>
</tbody>
</table>

Optimal TFSWeld has 4.08 μΩ joint resistance

Solid State Welding and Processing Technologies

Overview of Friction Stir Welding Variants
Friction Stir Welding Variants

Stationary Shoulder
Bobbin-Tool

Friction Stir Welding Variants
FSW Tool - Assisted by Joule Effect

Overview of Friction Stir Based Variants

Solid State Welding and Processing Technologies

✓ Overview of Friction Stir Based Variants
Friction Stir Based Variants

Friction Stir Embossing and Microforming

Near-Net Shaped Manufacture

Friction Stir Processing

Friction Stir Spot Welding

Embedding of SiC particles for FGM

Friction Stir Channeling

Friction Stir Channeling

Applications of Hybrid Friction Stir Channeling

Al-Al sample

Cu-Al sample

Friction Stir Channeling

Joining Aluminium to Polymer Based Component

Through Hole Extrusion Welding (THEW) – Aalto, Finland

Joining mechanisms:
- Mechanical interlocking
- Multi-directional joining
- Adhesion

Asymmetric Joint

Friction Stir Channeling

Friction Stir Channeling

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Friction Stir Channeling
Final Remark

Techniques based on Solid State Welding and Processing are in permanent advance since many centuries ago resulting in a wide range of solutions (from mature to modern breakthroughs) including some of the most impacting innovations in the Wonderful World Weldability (e.g. Friction Stir Welding)