Experimental investigation of magnetic pulse welding of ODS alloys

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FRANCE
Ecole Centrale Nantes

- 4 Research Laboratory
- 160 Researchers + Teaching
- 150 Admn. + Technical
- 13 Intl. Masters (3 Erasmus)
- 1600 Students
  
  1200 Engg, 230 Phd, 160 Masters

- Civil Engineering and Mechanics
- Fluid Mechanics
- Communication and Cybernetics
- Mathematics
Solide state welding group

Resp. Prof Guillaume Racineux

Equipments:
- FSW (Machining center. 3 and 5 axis, robot kuka 6 axis 500kg)
- LFW, RFW
- MPW

Simulation:
- Tools (comsol, Forge, Abaqus, LS Dyna)
  - simplified models

Modelisation / Simulation / Optimisation

Materials:
- Al
- TA6V, Inkonel, N18
- CMM, ODS,
- AL/Fe, Al/Cu

• Solid State Welding
  – Friction Stir Welding
  – Linear and Friction Welding
  – Magnetic Pulse Welding

• Forming
  – Magnetic and electro-hydro forming

Observation / testing:
- TEM, AFM, Optical Microscope
- X-ray tomography
- Dynamic and static traction,...

Materials:
- Al
- TA6V, Inkonel, N18
- CMM, ODS,
- AL/Fe, Al/Cu

1 Professor, 1 Research Engineer, 1 Engineer,
At present : 5 phd students
Plan

1. Introduction
   - Challenge to weld cases
   - Objective

2. Magnetic pulse welding (MPW)
   - Principle
   - Experiments
     - ODS alloy
   - Result
     - Optic
     - SEM
     - Micro hardness

3. Perspective
Impossible by Fusion Welding 1/2

Bimetallic Joints

Difficulty in Welding

Physical Properties
- Melting temperature
- Thermal conductivity
- Volumetric specific heat
- Coeff. thermal expansion

Unrealistic by Direct Fusion! → Solid State Welding

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A Metal Matrix Composite is a material which combines two different elements together

| Metallic Matrix (Al, Fe, Ti,..) | A ceramic or organic compound as reinforcement (Carbide, Graphite, Alumina) |

**Advantages**

- Physical Properties
- Improved specific strength
- Fatigue resistance
- Elevated temperature strength
- Wear resistance

Could be a solution for several applications

**But their Fabrication** 😞

Tem micrograph (Ferritic ODS)  
[Y. de Carlan et al, 2009]

Discontinuously reinforced Ti-Alloy

Fuel Tube

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Impossible by Fusion Welding 2/2
Metal Matrix Composite (MMC)/ODS

Difficulty in Welding

★ Formation of particle agglomerations during welding due to difference in density between the particles and the matrix.
★ Structural modifications of the materials due to large deformations.
★ Adverse chemical reactions between the particles and the matrix at high temperatures.

For welding Metal Matrix Composites without degrading its properties, should not melt the material

→ Solid State Welding

☒ Magnetic Pulse Welding (MPW)
☒ Friction Welding (FW)
☒ Diffusion Bonding

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To study the weldability of ODS alloy using MPW

★ High chrome ferritic steel with nanometric Y$_2$O$_3$ particle.
★ Due to its radiation resistance at high temperature ferritic ODS alloys are the preferred choice for Generation IV nuclear reactors as fuel cladding tubes
Magnetic Pulse Welding

Principle

- Similar to explosive welding (EXW)
- Acceleration → impact with very high velocity
- Configurations: tubes, plates & spot

Advantage
- No significant damage to base material

Difficulty
- Large Sections
- Bad Conductors (ODS)

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Magnetic Pulse Welding

Principle

TUBE CONFIGURATION

a) OUTER TUBE
INNER CORE

b) OUTER TUBE
INNER CORE

c) OUTER TUBE
INNER CORE

d : acceleration gap
α : angle of impact

JETTING

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Magnetic Pulse Welding
Choice of Parameters

- **Fixed process parameters**
  - Generator (C, L)

- **Parameters to chose**
  - Coil geometry (L, D, n) → (L_b, R_b)
  - Discharge energy: \( E = \frac{1}{2}CV^2 \)

- Frequency: \( f = \frac{1}{2\pi \sqrt{L_b C}} \)

- Skin thickness: \( \delta \approx \frac{1}{\sqrt{\mu \pi \alpha}} \)

### Magnetic Forming Generator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance (C)</td>
<td>360 µF</td>
</tr>
<tr>
<td>Inductance (L)</td>
<td>0,5 µH</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>8,3 KV</td>
</tr>
<tr>
<td>Energy (E)</td>
<td>12 KJ</td>
</tr>
</tbody>
</table>

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Experiments

Fig. part dimension

Fig. specimens

Fig. fixture

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Results

Fig. welded ODS alloy in G1 at XX kJ

Fig. welded MMC sample at XX kJ
Results

Fig. SEM image of weld interface welded in G2 at XX kJ

W. No. 2

Fig. SEM image of weld interface welded in G2 at XX kJ

W. No. 3
Results
Observation: Microscopy optic

W. No. 4

PEELING TEST →
Results

Observation : SEM
Results

Observation : X-ray dot mapping

(a) Yellow line indicating the zone of welding

(b) Fe

(c) Y

(d) O

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Results

Microhardness

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Conclusions

- application of MPW ODS alloys is demonstrated
- high energy is required to weld ODS alloys → use of pusher
- fusion type defects is observed in the end region → optimization
- further analysis of welded zone is required (TEM, high temperature Nitrogen gas test etc...)
Merci
Thank You
Questions??