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Experimental investigation of magnetic pulse welding of ODS alloys

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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

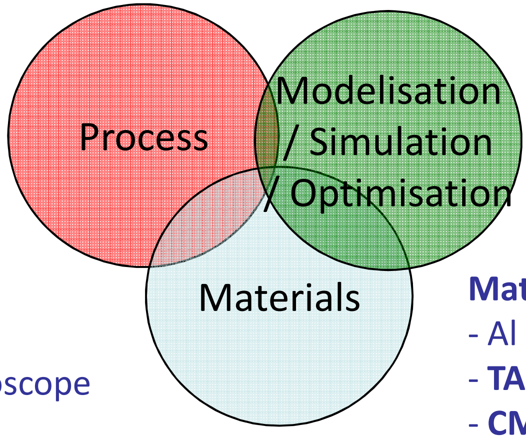
- Civil Engineering and Mechanics
- Fluid Mechanics
- Communication and Cybernetics
- Mathematics




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

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

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

- **Magnetic forming/welding equipments**
  - 5 forming generators (30kJ, 18kJ, 16kJ, 12kJ
  - 1 welding generator (18kJ)

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

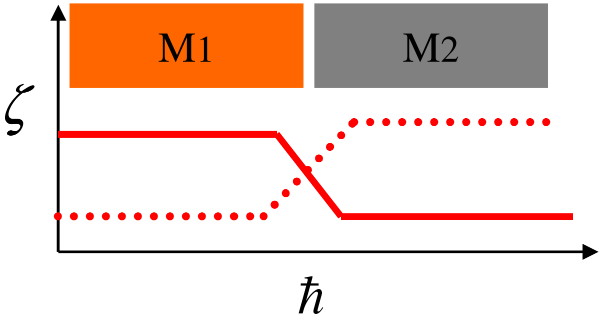
Plan

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

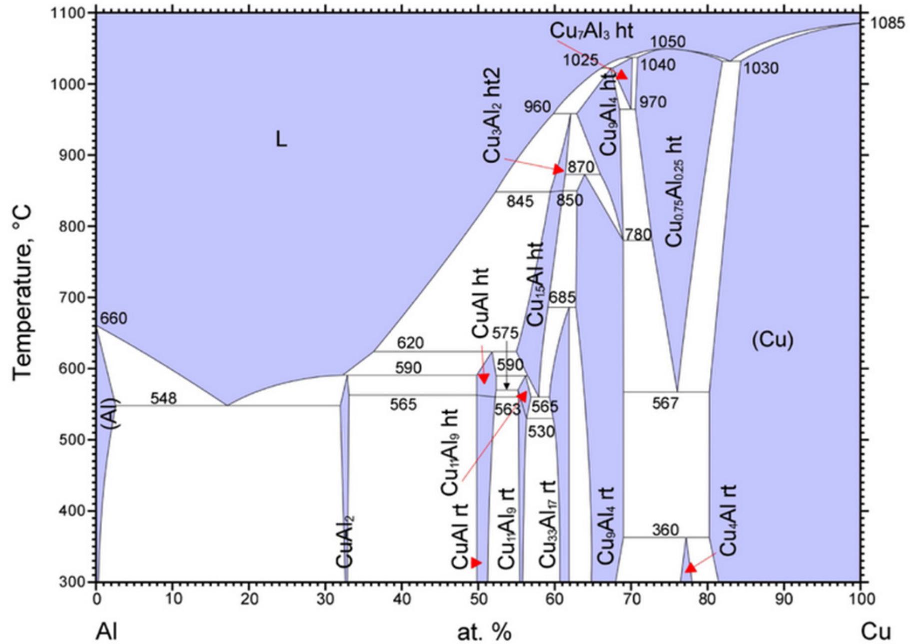
Bimetallic Joints

Difficulty in Welding



⌧Physical Properties

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



⌧ Formation of Intermetallic phases

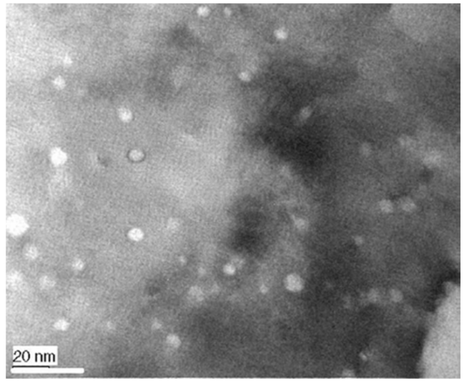
Unrealistic by Direct Fusion ! → Solid State Welding

Impossible by Fusion Welding 2/2

Metal Matrix Composite (MMC)/ODS

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)



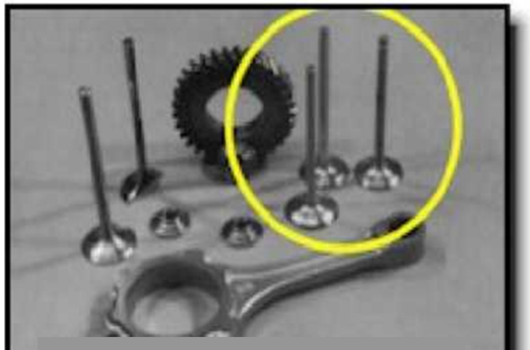
TEM micrograph (Ferritic ODS)
[**Y. de Carlan et al, 2009**]

Advantages

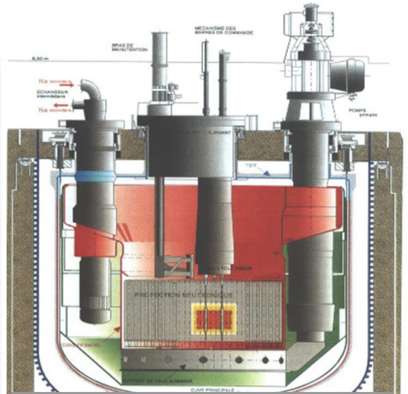
- Physical Properties
- Improved specific strength
- Fatigue resistance
- Elevated temperature strength
- Wear resistance

Could be a solution for several applications

But their Fabrication



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

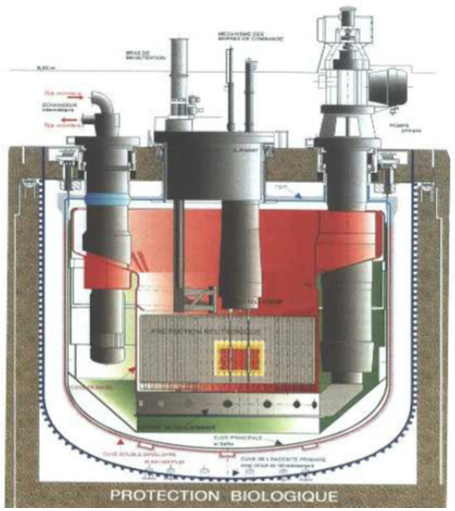
→ Solid State Welding 

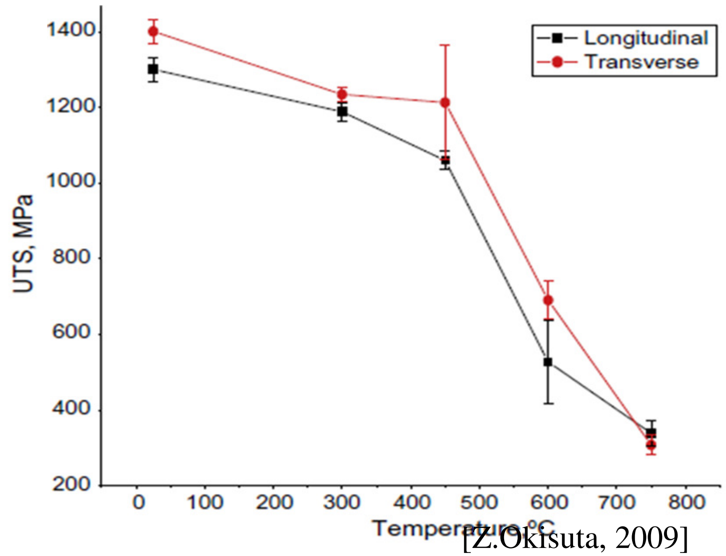
- ⌧ Magnetic Pulse Welding (MPW)
- ⌧ Friction Welding (FW)
- ⌧ Diffusion Bonding

Objective

To study the weldability of ODS alloy using MPW

- ★ High chrome ferritic steel with nanometric Y_2O_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

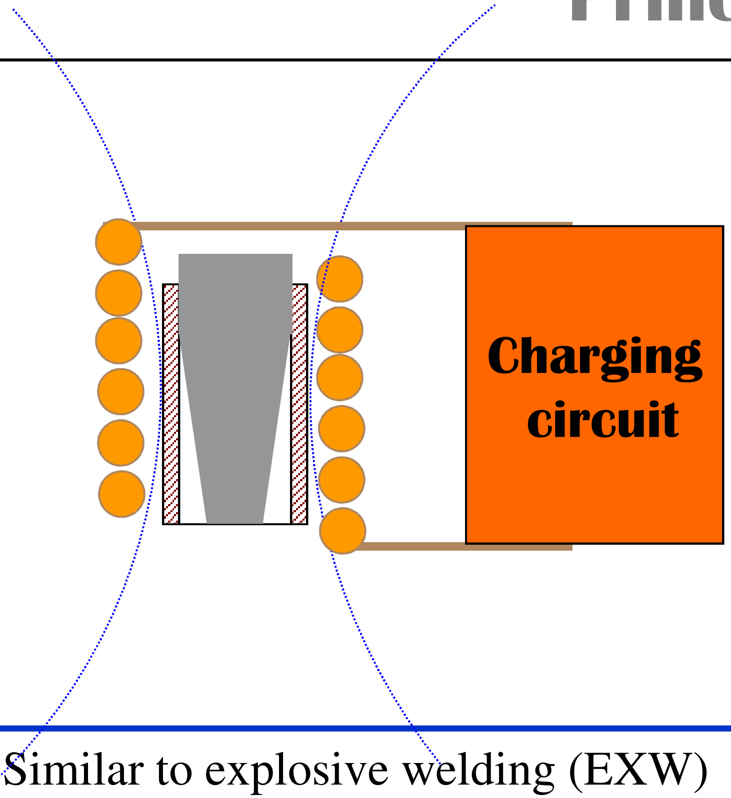


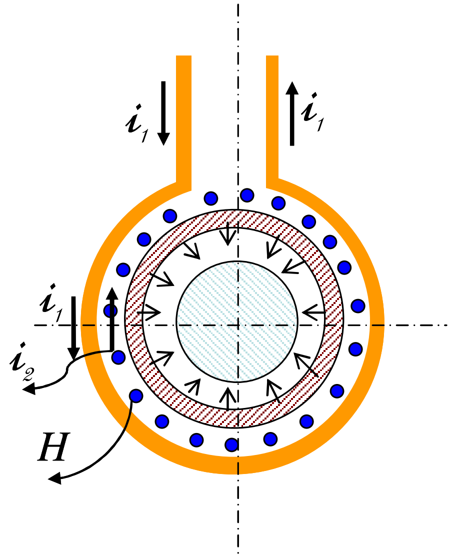


[Z.Okisuta, 2009]

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

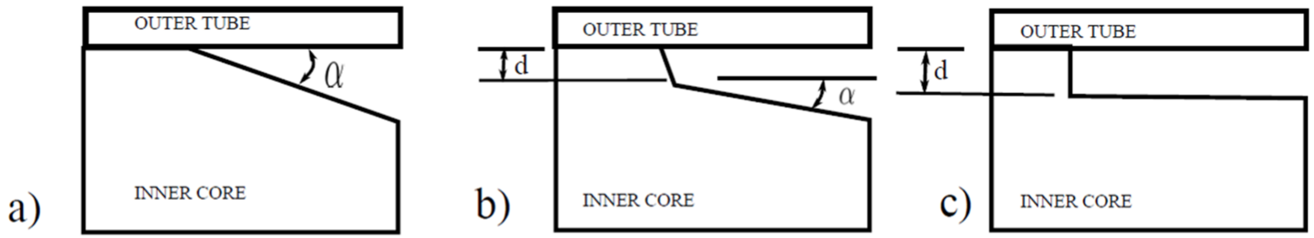
Difficulty

- ❑ Large Sections
- ❑ Bad Conductors (ODS)

Magnetic Pulse Welding

Principle

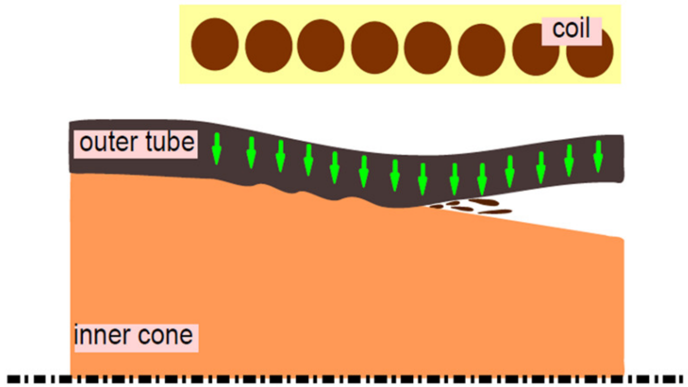
TUBE CONFIGURATION



d : acceleration gap

α : angle of impact

JETTING



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Magnetic Pulse Welding

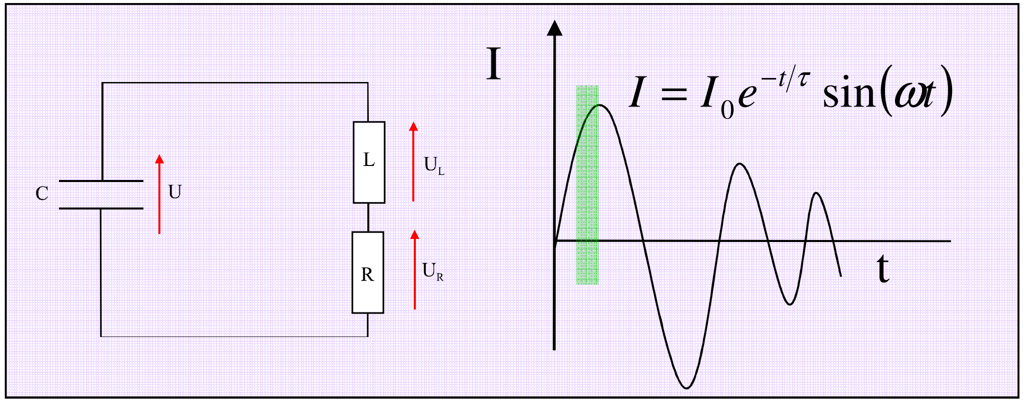
Choice of Parameters

★ **Fixed process parameters**

- Generator (C, L)

★ **Parameters to chose**

- Coil geometry (Ln, D, n) → (L_b, R_b)
- Discharge energy: $E=1/2CV^2$



- Frequency $f = \dfrac{1}{2\pi\sqrt{L_b C}}$
- Skin thickness $\delta \approx \dfrac{1}{\sqrt{\mu\pi f \alpha}}$

Magnetic Forming Generator

Capacitance (C)	360 µF
Inductance (L)	0,5µH
Voltage (V)	8,3 KV
Energy (E)	12 KJ

Experiments

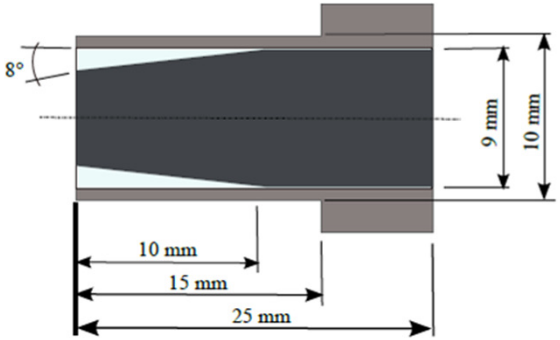


Fig. part dimension

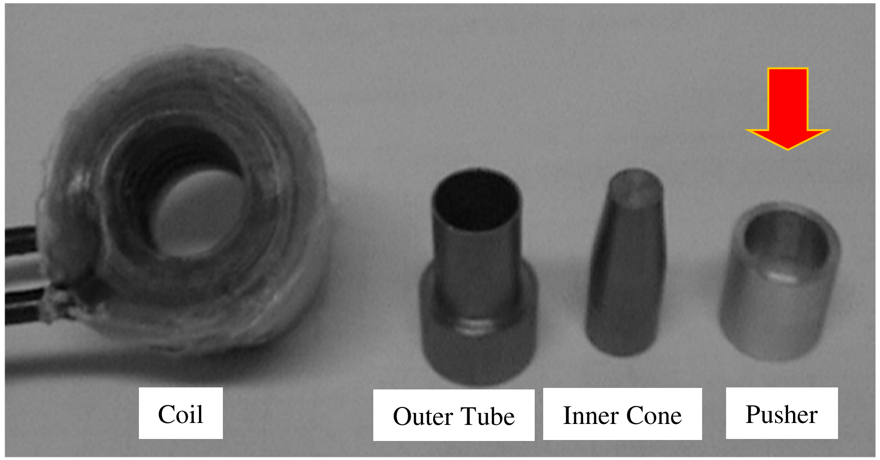


Fig. specimens

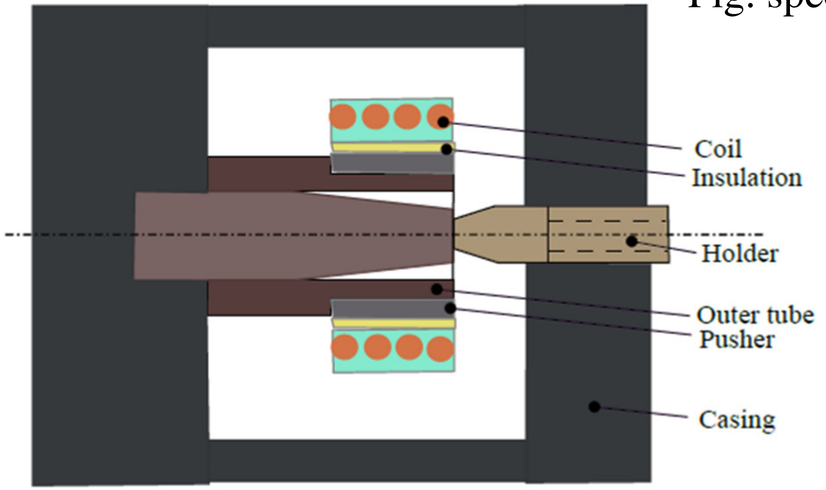


Fig. fixture

Results

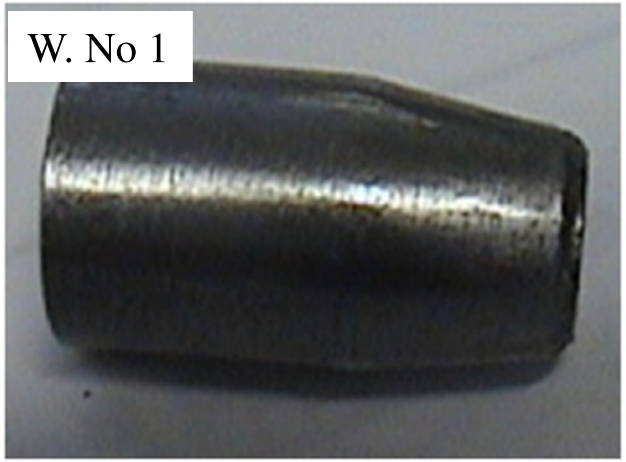


Fig. welded ODS alloy in G1 at XX kJ

Fig. welded MMC sample at XX kJ

Results

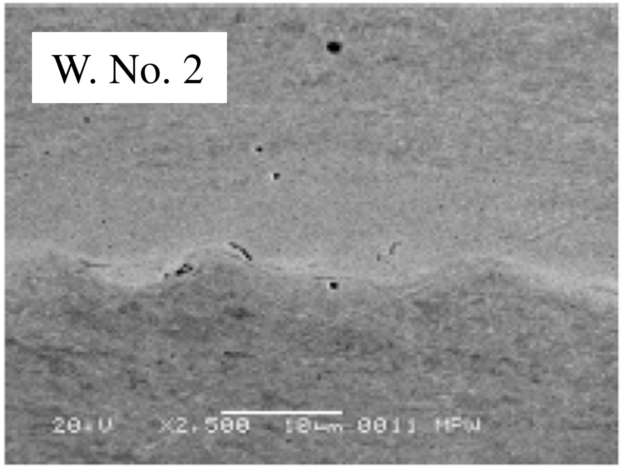


Fig. SEM image of weld interface welded in G2 at XX kJ

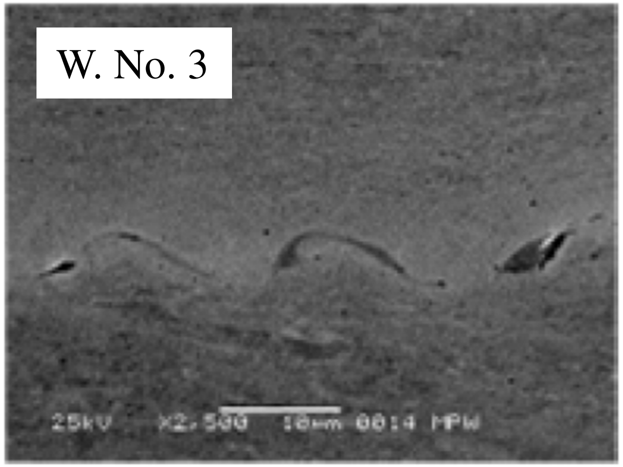


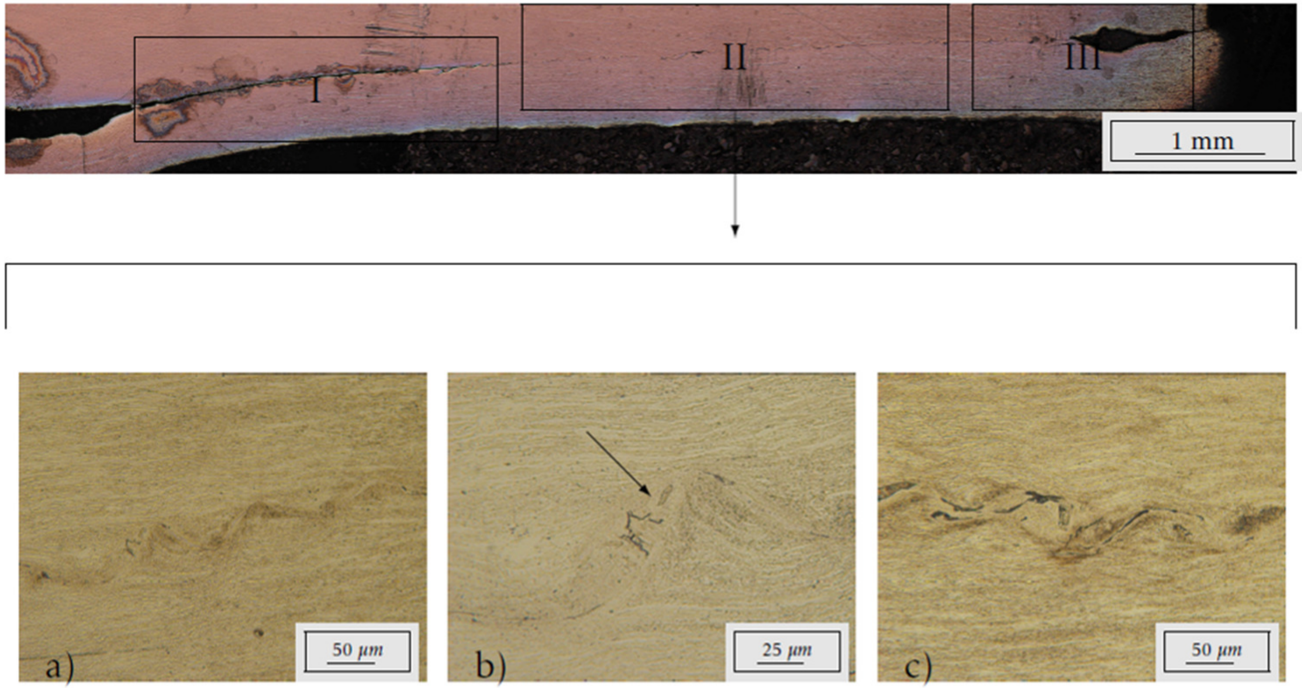
Fig. SEM image of weld interface welded in G2 at XX kJ

Results

Observation : Microscopy optic

W. No. 4

PEELING TEST →



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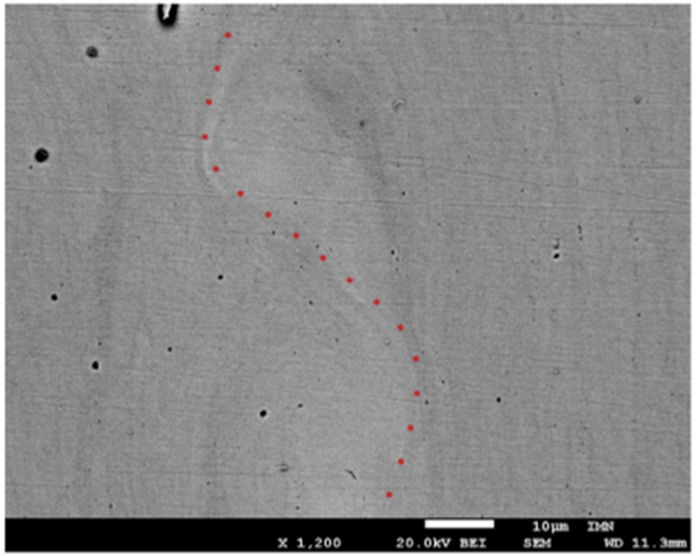
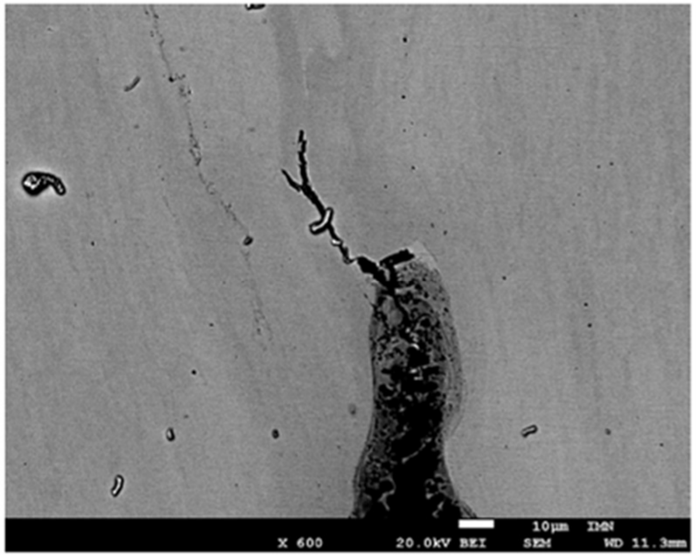
Results

Observation : SEM





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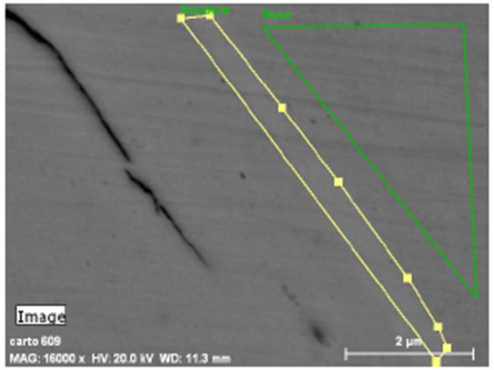
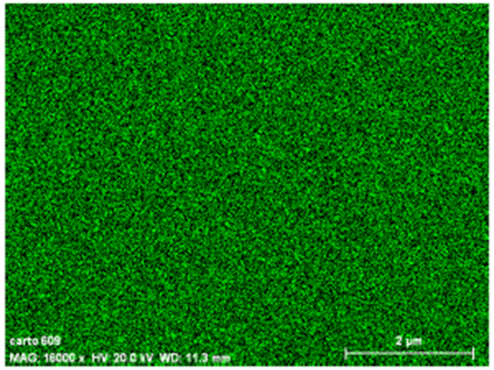
Results

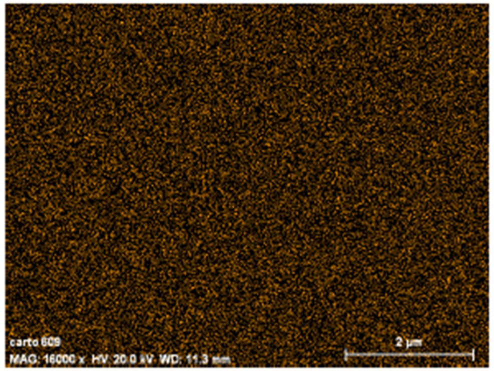
Observation : X-ray dot mapping



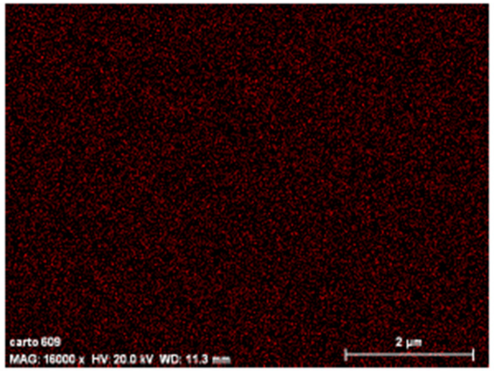
(a) Yellow line indicating the zone of welding



(b) Fe



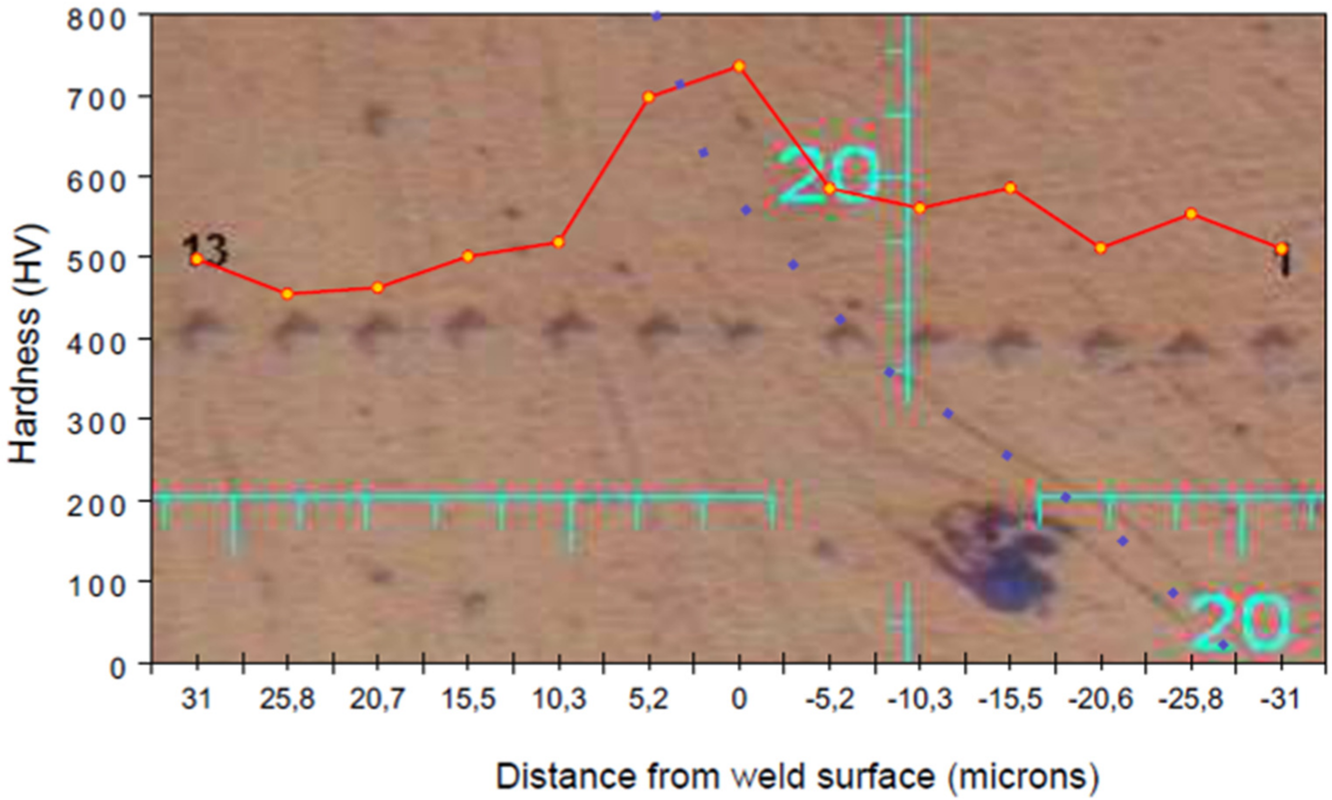
(c) Y



(d) O

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..,)

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Merci

Thank You

Questions??