Aalto University

OPEN ACCESS

This is an electronic reprint of the original article.
This reprint may differ from the original in pagination and typographic detail.

Vilaça, Pedro; Sorger, Gonçalo

Advanced Control of FSW of Ultra-HSSteels Based on the Monitoring of the Magnetic Permeability of the Processed Zone

Published in:
12th Meeting SVETS Kommissionen AG 52 - FSW Processing, May 27, 2015, Oskarshamn, Sweden

Published: 01/01/2015

Document Version
Early version, also known as pre-print

Please cite the original version:
Vilaça, P., & Sorger, G. (2015). Advanced Control of FSW of Ultra-HSSteels Based on the Monitoring of the Magnetic Permeability of the Processed Zone. In *12th Meeting SVETS Kommissionen AG 52 - FSW Processing, May 27, 2015, Oskarshamn, Sweden*

This material is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.

Aalto University
School of Engineering

Department of Engineering

Design and Production

Engineering Materials

Advanced Control of FSW of Ultra-HS Steels

… based on the monitoring of the magnetic permeability of the processed zone

Pedro Vilaça and **Gonçalo Sorger**

Aalto University, Espoo, Finland

27th May 2015

Application of FSW to UHSS

Objectives

☞ Innovative solutions

✓ **Supported by advanced monitoring control**

✓ Superior properties of weld zone

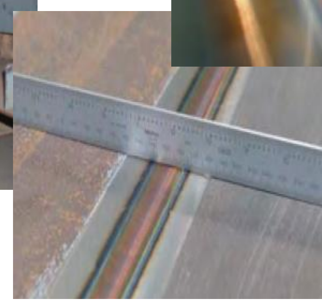
✓ Low residual stresses and distortion

☞ Technological conditions:

✓ Simple joint preparation

✓ Low heat input

✓ Development of experimental conditions



☞ Metallurgical + Mechanical Characterization

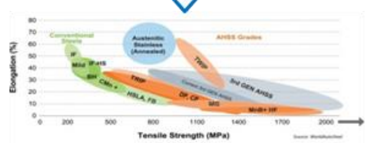
☞ **Establishment of new weldability paradigm for novel UHSS**

Solves the limited weldability of Ultra High-Strength Steels (UHSS) with no limitation related with the level of strength

FSW dedicated for novel UHSS

New weldability paradigm for novel UHSS

Advanced online monitoring and control system for FSW of Ultra HSSteels

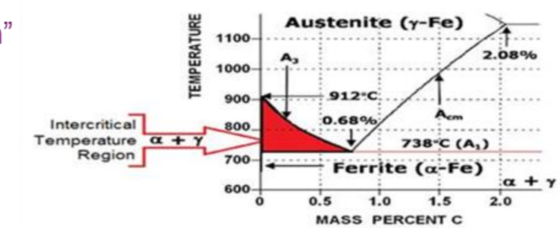


…To solve typical weldability defects (with fusion welding):

- Properties **Mismatch @ Weld metal**
- **Loss** of strength/toughness @ **HAZ**
- **Inclusions & Porosity**
- **Cracking** (hydrogen, reheat, lamellar tearing, fatigue induced)

Solution: Solid-state processing within the "intercritical temperature region"

$$T_{A1} < \max T_{FSW} < T_{A3}$$



Inovative integrated **On-line Monitoring and Control** strategy

On-line Monitoring
(of relevant physical phenomena)

- **Temperature [T]**
- **Strain rate [ε]**

(using NDT techniques)

- **Magnetic field measurements**
- **IR Camera / Thermocouples (for validation)**

+

Closed-Loop Control
(of main FSW parameters)

- **Forging Force [F_Z]**
- **Weld Pitch Ratio [Ω/v]**
- **Torque [N.m]**
- **Pre-heat [T_0]**

=

Deliverable Features

- **↑ Properties of WM & HAZ (near matching or even overmatching BM)**
- **No defects + smooth weld bead shape**
- **↓ Flow Stress + ↓ Tool Temperature = ↓ Tool Wear**
- **↓ Heat Input = ↓ HAZ size + ↓ Residual Deformation**

(+ full mechanical and metallurgical analysis)

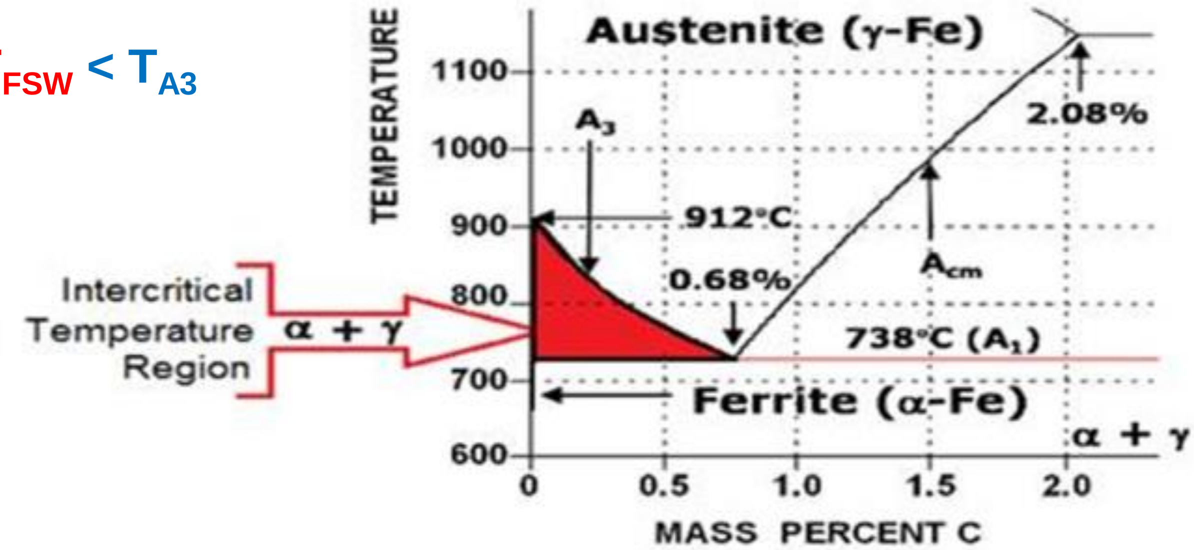
FSW dedicated for novel UHSS

New weldability paradigm for novel UHSS

⇨ **Autogeneous weld zone processed within the intercritical temperature region:**

…prevents full austenitization within weld, during heating period, and upon cooling, results in properties that are known to correspond to best overall condition

$T_{A1} < \max T_{FSW} < T_{A3}$



⇨ **Low Heat Input** enables the retaining of the original properties and low residual deformation

Benefits from ICHAZ

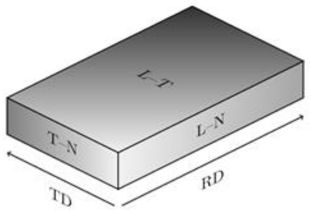
Case Study in Fusion GMAW of UHSS (1/4)

- **Optim 960 QC** (plate 86061-011): thickness, $\boldsymbol{t}$ **= 10 mm**
  - *Composition [wt%]:*

C	Si	Mn	P	S	Al	Nb	V	Cu
0.092	0.187	1.10	0.010	0.0012	0.033	0.002	0.011	0.014
Cr	Ni	N	Mo	Ti	Ca	B	Co	
1.14	0.398	0.0054	0.183	0.023	0.0017	0.0022	0.016	

  - *CEV = 0.57 (* CEV_{max} *= 0.62) - Note: CEV > 0.42* $\Rightarrow$ *special precautions (e.g.* T_0*)*
  - *Hardness = 380 HV30*

Location	T–N [HV1]	L–N [HV1]
2 mm from bottom	373	385
Mid-thickness	379	386
2 mm from top	377	388

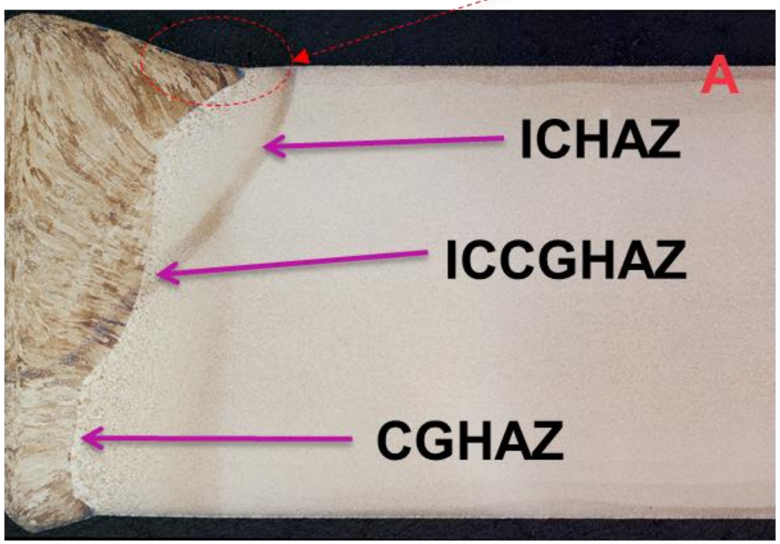


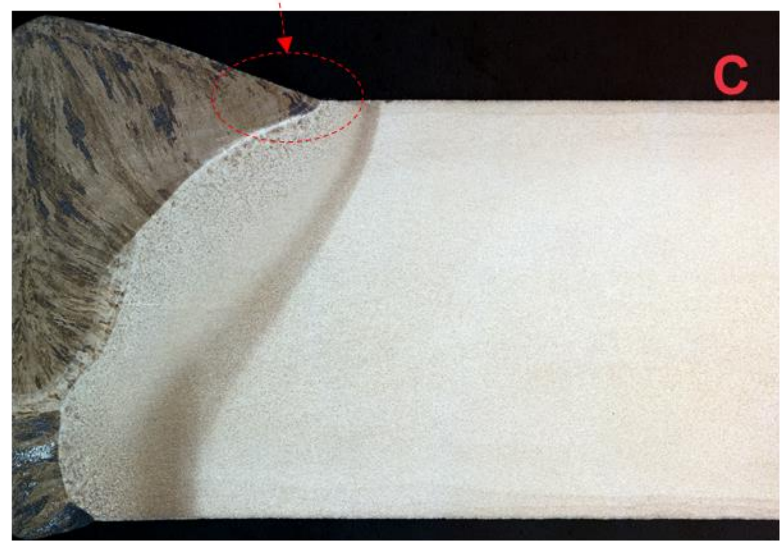
Benefits from ICHAZ

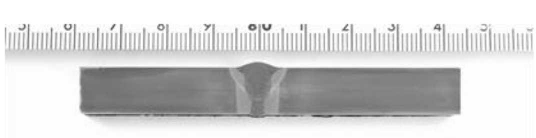
Case Study in Fusion GMAW of UHSS (2/4)

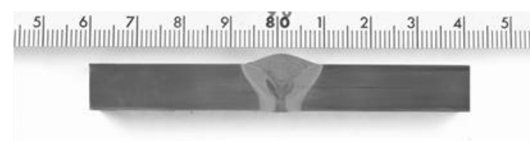
Different angle… but good weld toe shape

Focus on the HAZ



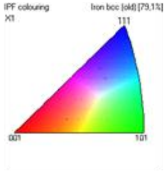




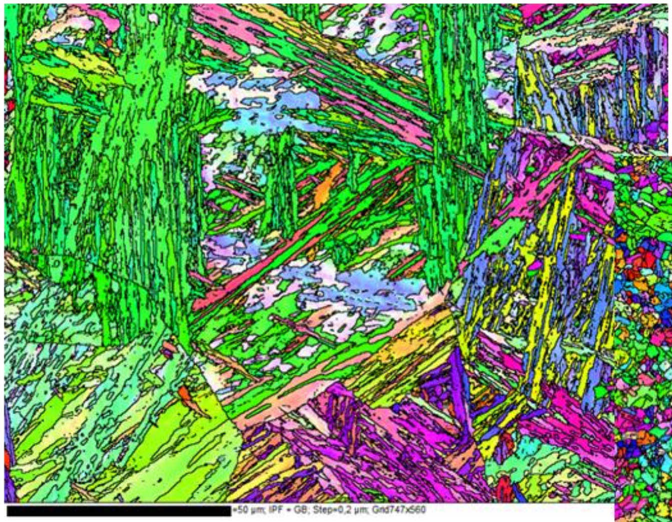


Benefits from ICHAZ

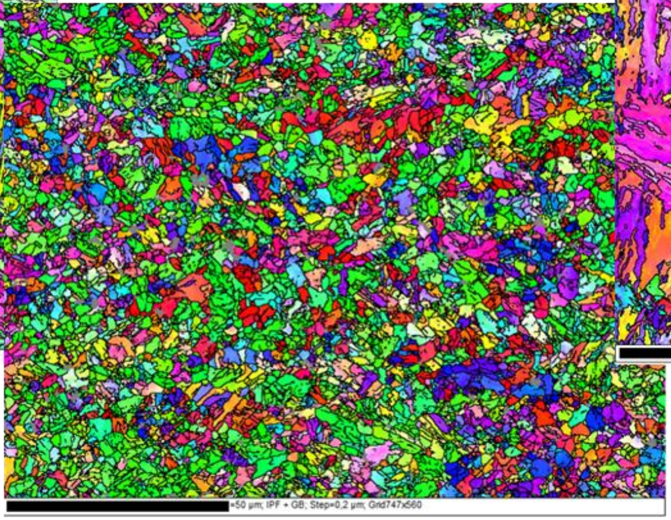
Case Study in Fusion GMAW of UHSS (3/4)



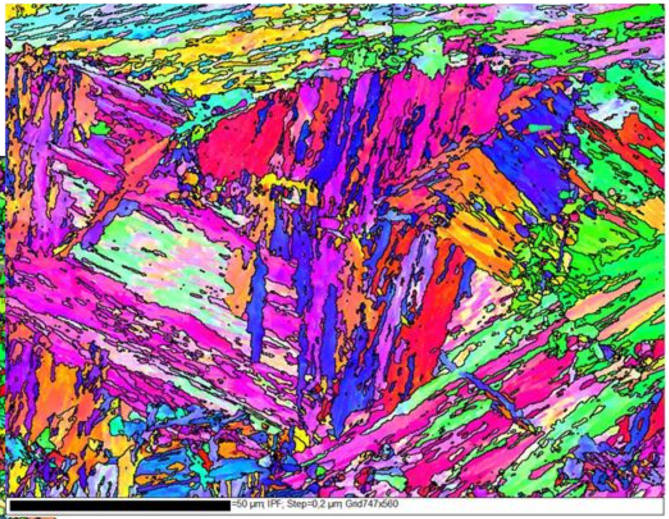
CGHAZ (1.2 kJ/mm)



ICHAZ (1.2 kJ/mm)

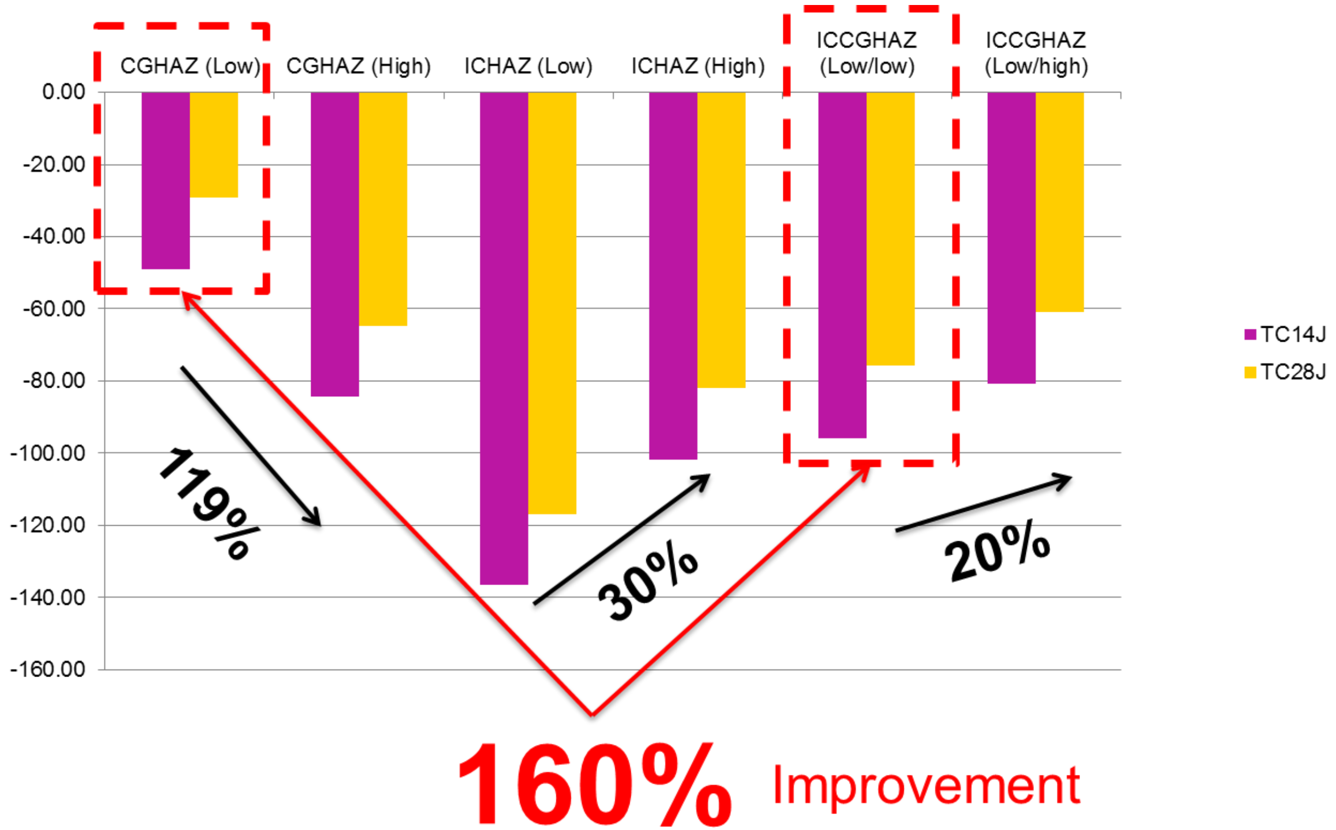


ICCGHAZ (0.8/1.2 kJ/mm)



Benefits from ICHAZ

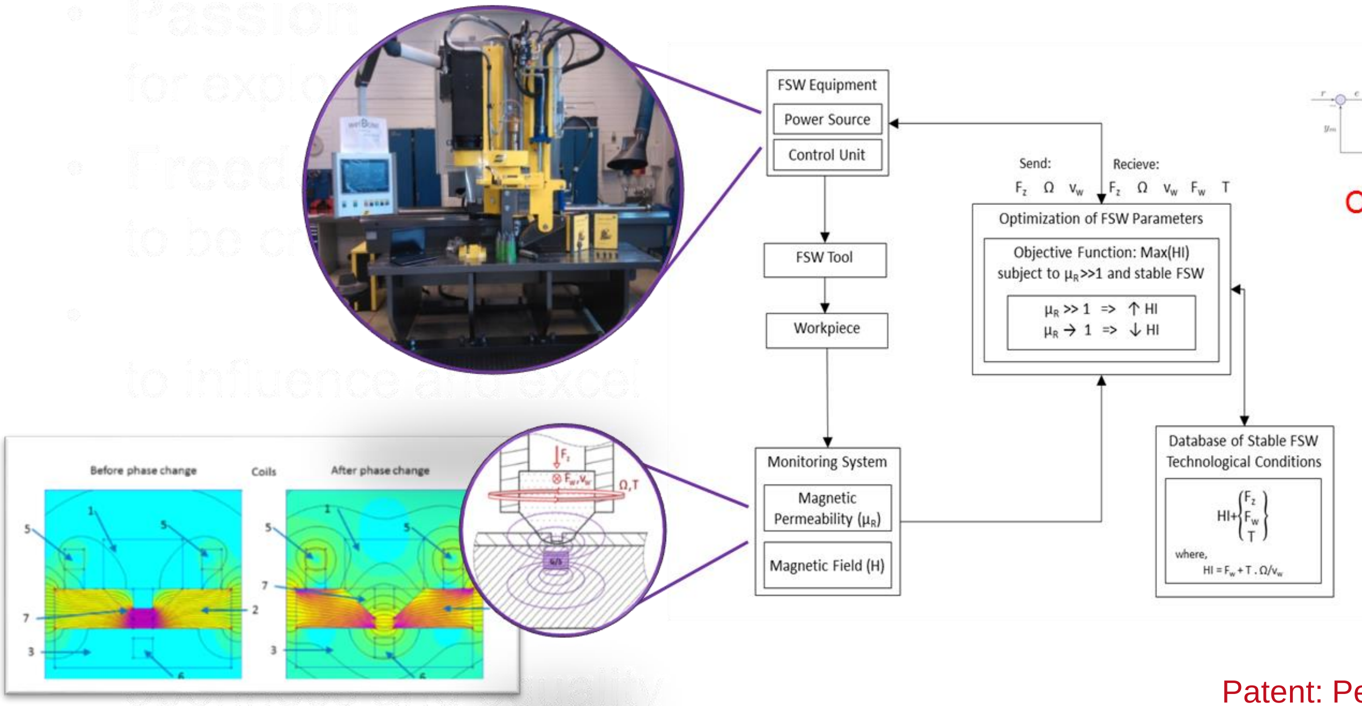
Case Study in Fusion GMAW of UHSS (4/4)

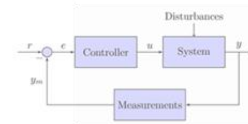


FSW dedicated for novel UHSS

Advanced Control Fundaments

Control of friction stir processing and welding parameters based on monitoring the magnetic permeability of the processed zone





Closed-loop process control

Patent: Pedro Vilaca et al.
(US 62/129051 - 06/03/2015)

FSW dedicated for novel UHSS

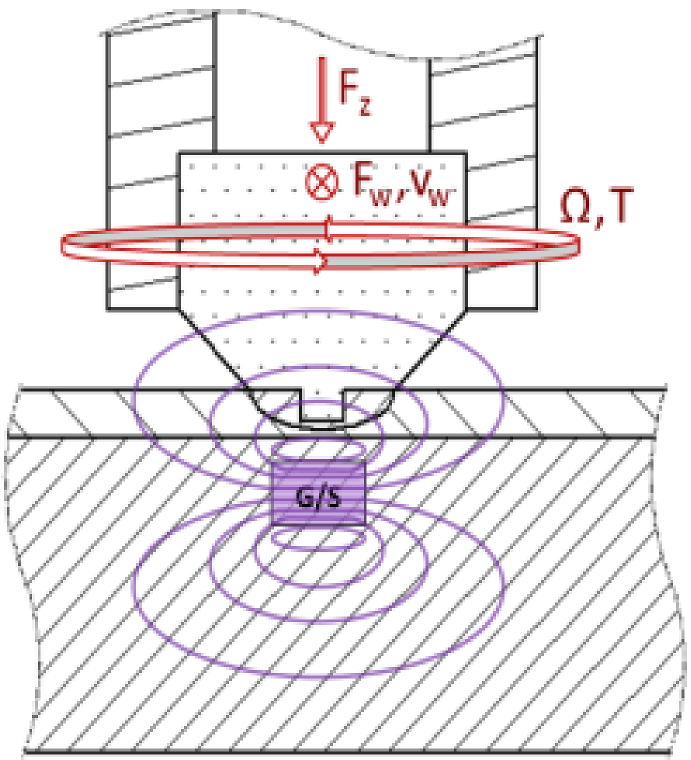
Advanced Control Fundaments

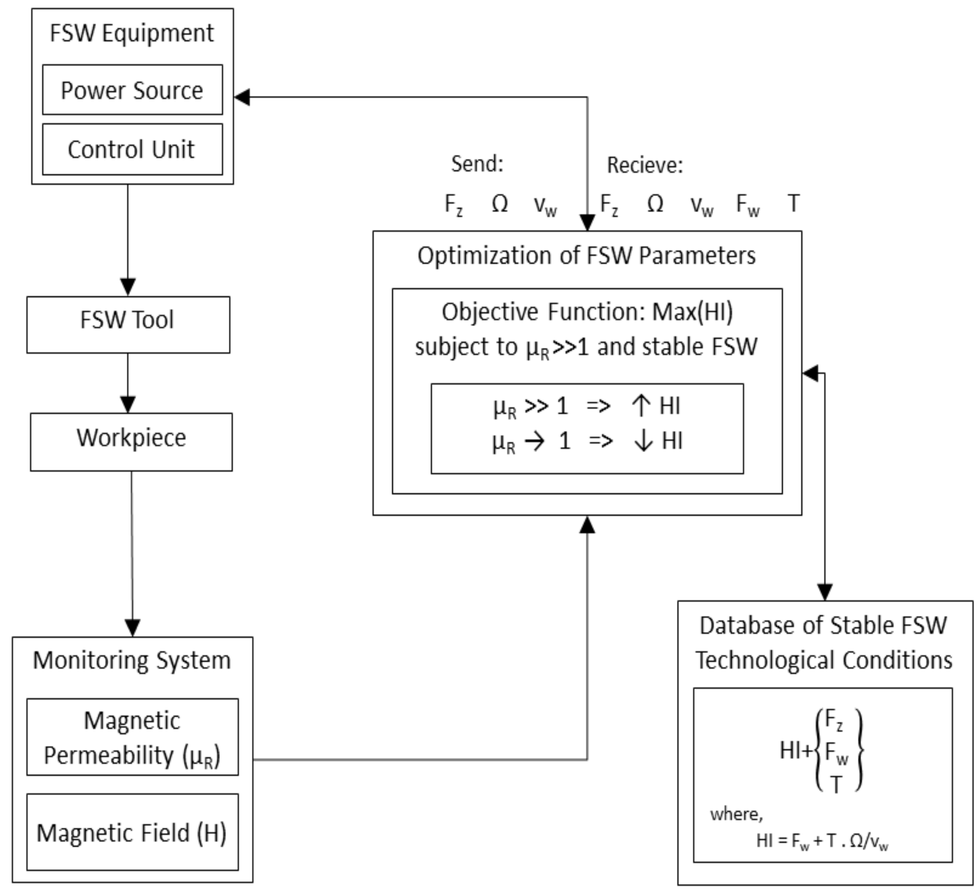
☞ All the low alloy steels undergo a significant change of its magnetic permeability (μ_R) within the intercritical temperature region, where the Curie temperature lays

☞ For these materials the significant change of magnetic permeability (μ_R) within the intercritical temperature region, strongly affects the magnetic permeability (μ_R) in the weld and its effect is detected by the magnetometer sensors, providing information to support the optimization of the FSW parameters

FSW dedicated for novel UHSS

Advanced Control Fundaments: Overall System

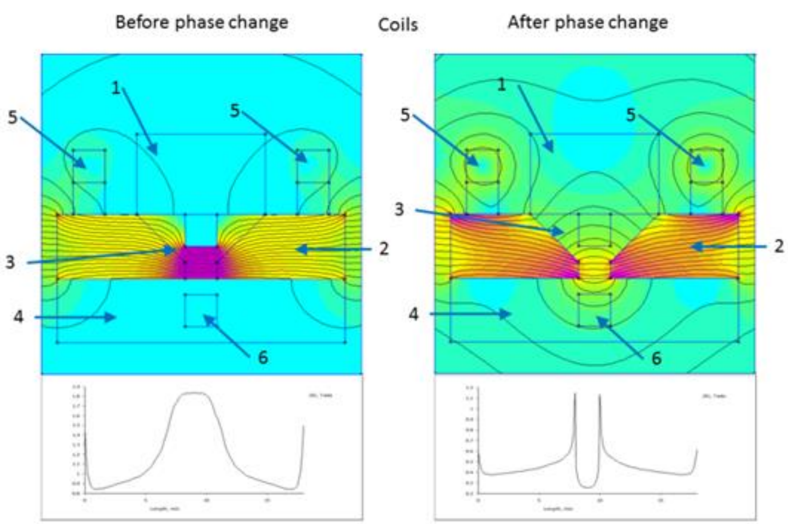


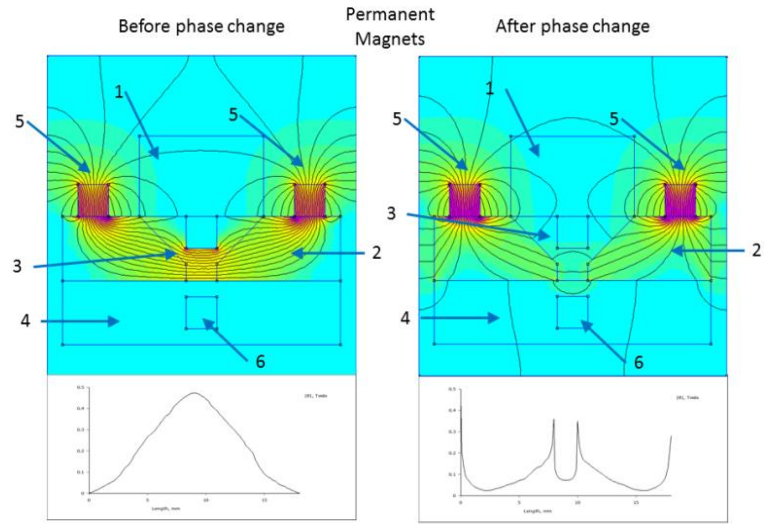


FSW dedicated for novel UHSS

Advanced Control Fundaments: Monitoring System

- Magnetic field generators/sensors establish a magnetic field in the processed zone and measure the changes induced by modifications of the magnetic permeability (μ_R) in the TMAZ
- The control system enables contactless solution





Conclusions

☞ *The Advanced Control of FSW of Ultra-HS Steels*

… based on the monitoring of the magnetic permeability of the processed zone

- Undergoing proof of concept
- High potential for FSWelding + FSProcessing of fusion weld joints and casted components