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

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SVETS Kommissionen
AG 52 FSW Processing

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Application of FSW to UHSS

Objectives

☞ Innovative solutions

✓**Supported by advanced monitoring control**

✓Superior properties of weld zone

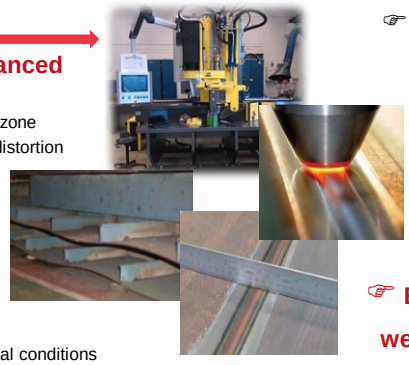
✓Low residual stresses and distortion

☞ Technological conditions:

✓Simple joint preparation

✓Low heat input

✓Development of experimental conditions



☞ Metallurgical + Mechanical Characterization

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

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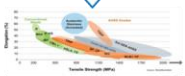
New weldability paradigm for novel UHSS

Advanced online monitoring and control system for FSW of Ultra HSSteels

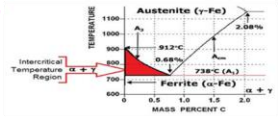


…To solve typical weldability defects (with fusion welding):

- 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)

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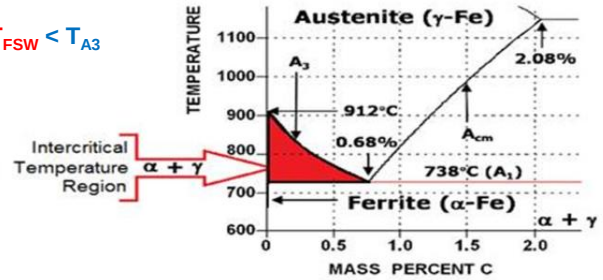
New weldability paradigm for novel UHSS

⇨ **Welding at 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

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



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Benefits from ICHAZ

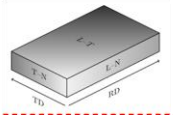
Case Study in Fusion GMAW of UHSS (1/4)

- **Optim 960 QC** (plate 86061-011): thickness, 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 ⇒ special precautions (e.g. T_o)*
  - *Hardness = 380 HV30*

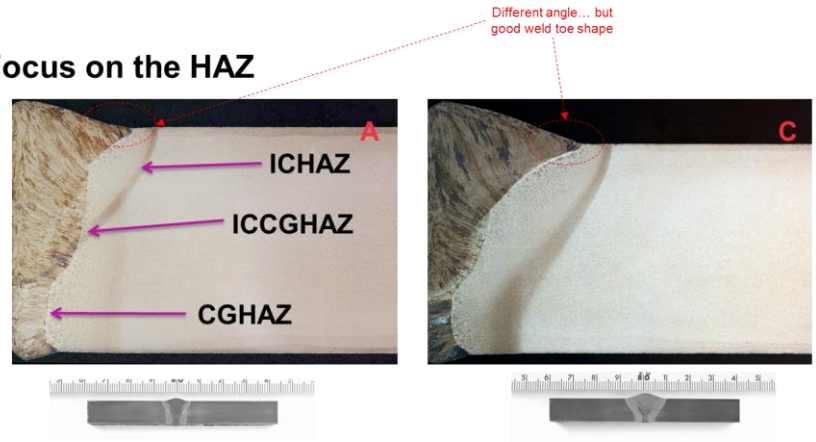
Location	T–N [HV1]	L–N [HV1]
2 mm from bottom	373	385
Mid-thickness	379	386
2 mm from top	377	388



Benefits from ICHAZ

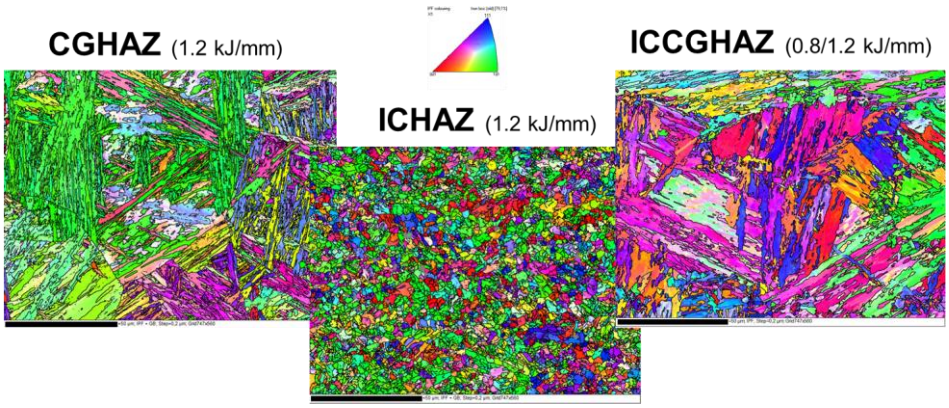
Case Study in Fusion GMAW of UHSS (2/4)

Focus on the HAZ



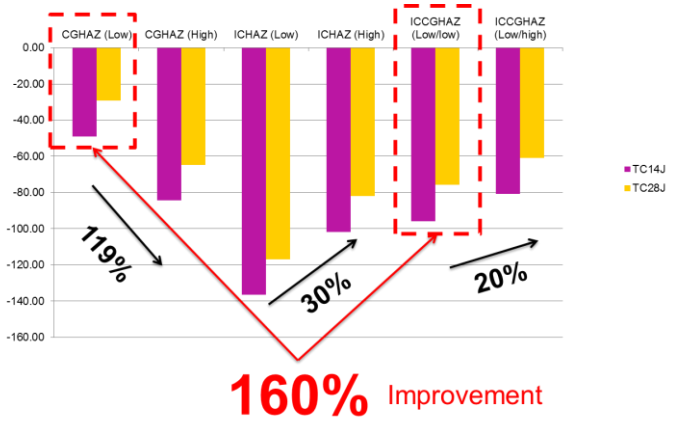
Benefits from ICHAZ

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



Benefits from ICHAZ

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



160% Improvement

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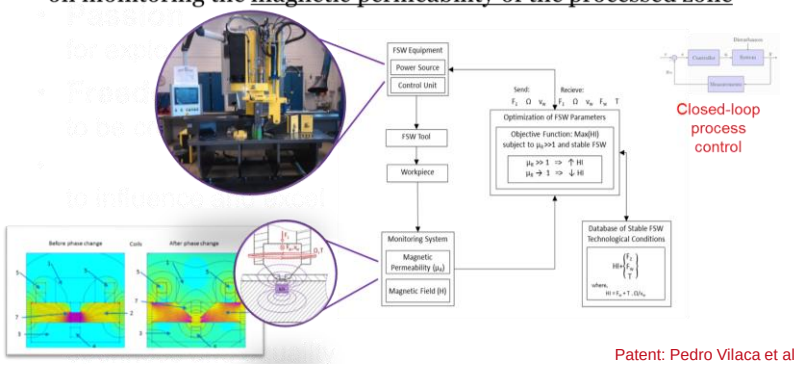
Advanced Control Fundaments

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



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

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Advanced Control Fundaments

- ☞ All the low alloy steels undergo a significant change of its magnetic permeability (μR) within the intercritical temperature region, where the Curie temperature lays
- ☞ For these materials the significant change of magnetic permeability (μR) within the intercritical temperature region, strongly affects the magnetic permeability (μR) in the weld and its effect is detected by the magnetometer sensors, providing information to support the optimization of the FSW parameters

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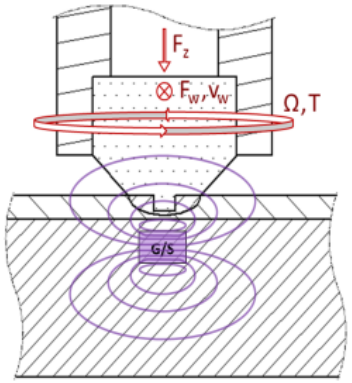
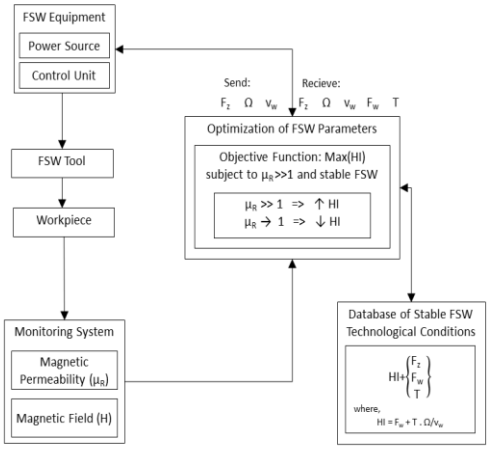
Advanced Control Fundaments





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