



Aalto University
School of Engineering

Department of Engineering
Design and Production

Engineering Materials

FSW ASSISTED BY ELECTRICAL JOULE EFFECT TO OVERCOME LACK OF PENETRATION IN ALUMINIUM ALLOYS

Telmo G. Santos, Rosa M. Miranda @ FCT-Univ. Nova de Lisboa, Portugal

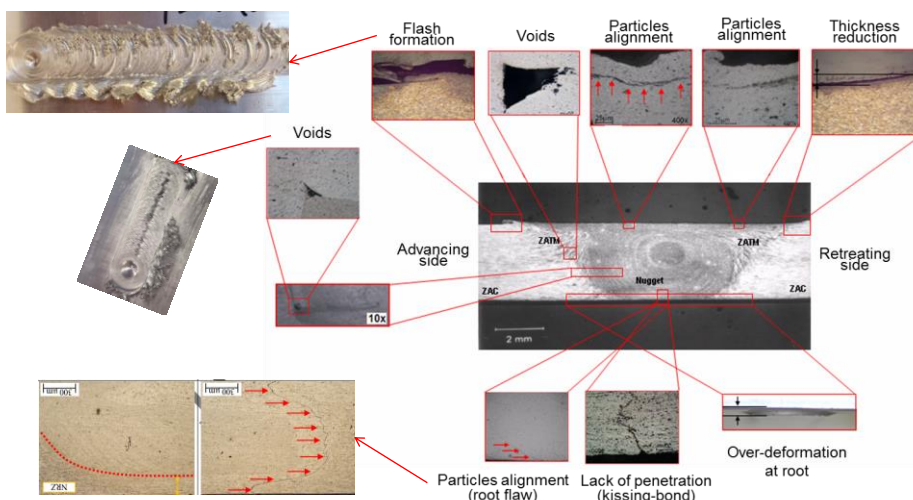
Pedro Vilaça @ Aalto University, Espoo, Finland

11th Meeting
SVETS Kommissionen
AG 52 FSW Processing

23rd September 2014
Aalto University, Finland

Possible Imperfections in Conventional FSW

Butt Joints



Most of Imperfections are Easy to Avoid ...with Correct Technological Conditions



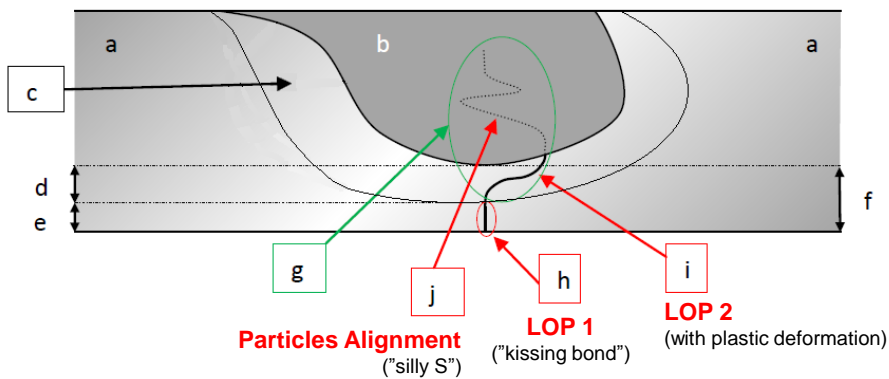
6m length butt weld in steel S355



Figure 11. Nobel Peace Centre, Oslo Norway. The canopy is a temporary installation by David Adjaye that serves as a gateway between Oslo City Hall where the Peace Prize Ceremony takes place and the Nobel Peace Centre. The canopy has been manufactured with the FSW process. Photo: Timothy Scar / Adjaye Associates.

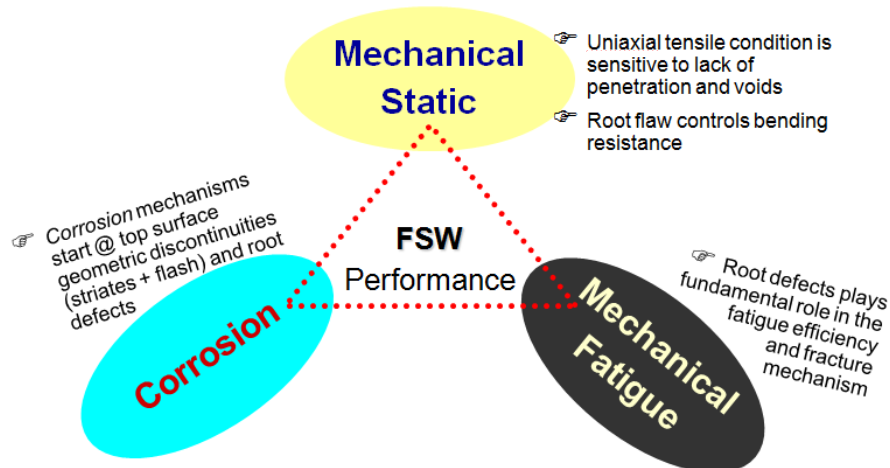
Root Defects in Conventional FSW

Particles Alignment at the Root is Difficult to Avoid



Effect of Defects in Conventional FSW

Mechanical and Corrosion Resistance



Problem to Solve

Root defects (e.g. LOP) constitutes a major constrain to a wider dissemination of conventional FSW into industry, especially when aluminium alloys are to be welded

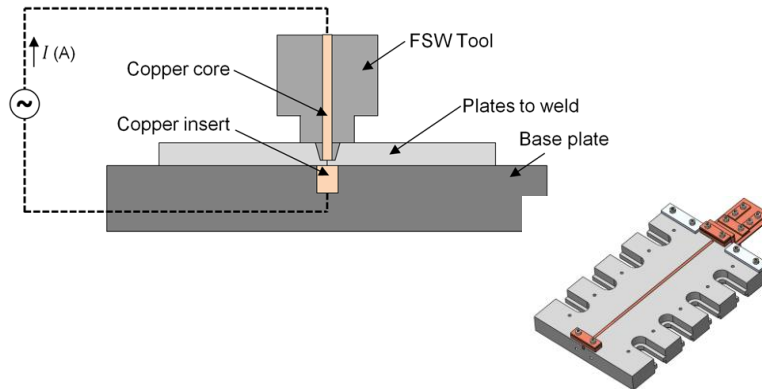
Solution to Implement and Test

Assisting FSW with an external electrical heat source supplied via the tool to:

1. To increase the temperature locally @ Weld Root (without increasing HI and affect HAZ)
2. To improve locally the material viscoplasticity via reducing the flow stress

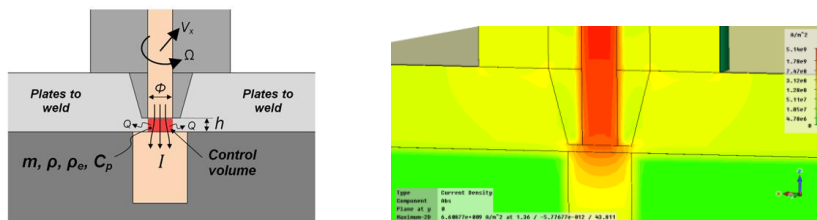
Solution Implemented

Assisting FSW with an External Electrical Heat Source



Local Heat Input

Heat Generated via Joule Effect

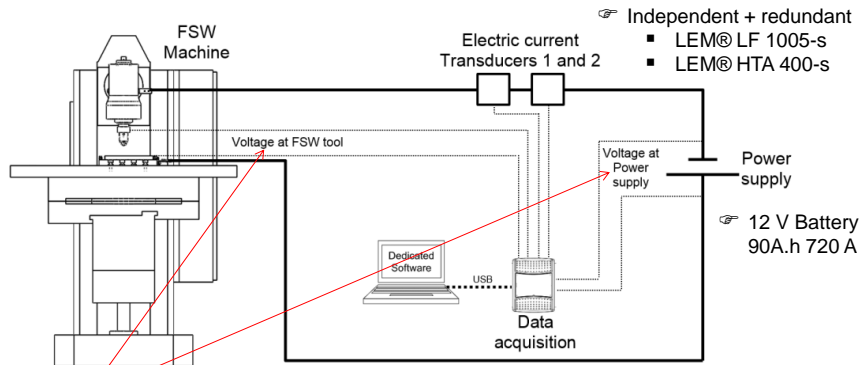


$$Q_{\text{Joule Effect}} = Q_{\text{Increase temperature}}$$

$$R \cdot I^2 \cdot t = m \cdot C_p \cdot \Delta T$$

Equipment

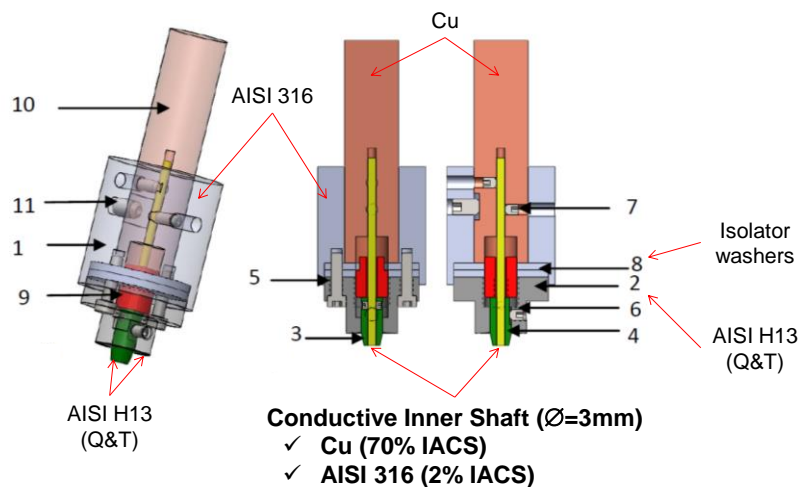
Overall Installation with Electronics and Data Acquisition



- ✓ V @ power supply terminals and between the tool body and the base plate
- ✓ Data acquisition system (DAQ) NI USB-9008 with frequency 5Hz
- ✓ Dedicated software was developed in LabVIEW® to monitor + save data

FSW Tool Assisted by Electrical Current

The Components and Materials



Experimental Implementation

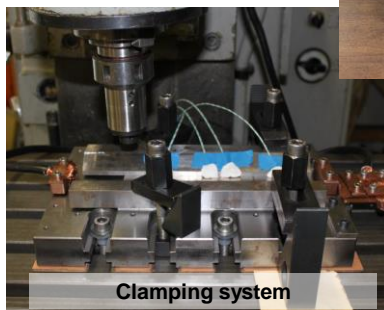
Process Parameters and Implementation Details



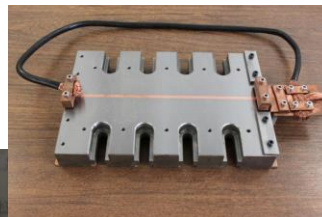
Electrical connectors
attached to the head of
the milling machine

FSW Parameters:

- ✓ $\Omega = 1120$ rpm
- ✓ $V = 200$ mm/min
- ✓ $\alpha = 1.5^\circ$



Clamping system



Anvil
with the inserted
conductive copper bar

FSW Tool Features

Detail on the Conductive Inner Shaft

Shoulder:

- ✓ $\varnothing = 16$ mm
(Smooth +
Concave 7°)



- ✓ **Cu (100% IACS)**

Conductive Inner Shaft ($\varnothing = 3$ mm)

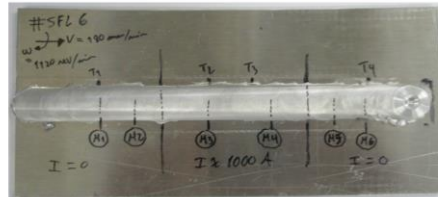
- ✓ **AISI 316L (2% IACS)**



Probe:

- ✓ 6mm \leftrightarrow 4mm conical
- ✓ ISO threaded
- ✓ Length = 3.5 mm \Rightarrow LOP \approx 0.5 mm

Joints and Electrical Parameters Conductive Inner Shaft Made of Copper (Cu)

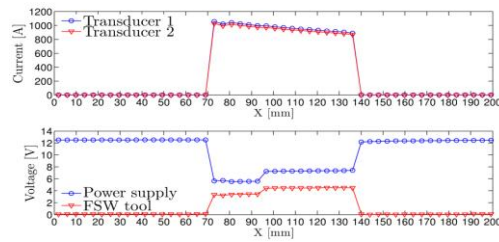


AA6082-T6

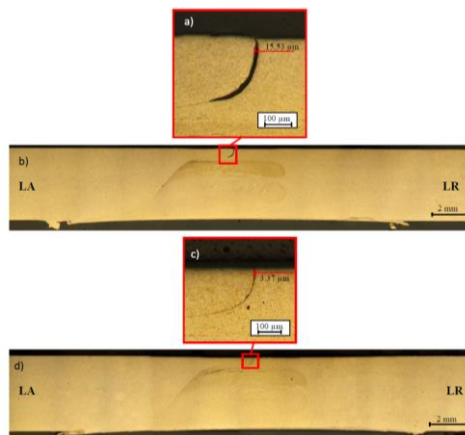
FSW along rolling direction

210 mm x 103 mm

✓ Thickness: 4 mm

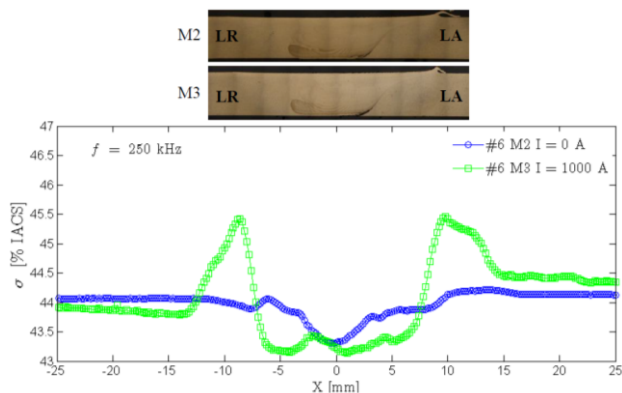


Joints and Electrical Parameters Conductive Inner Shaft Made of Copper (Cu)



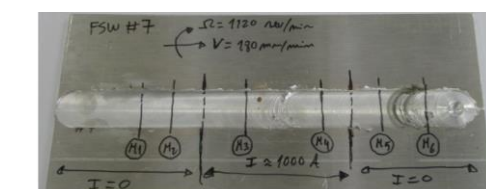
Electrical Conductivity @ Root Surface

Conductive Inner Shaft Made of Copper (Cu)



Joints and Electrical Parameters

Conductive Inner Shaft Made of Stainless Steel AISI 316L

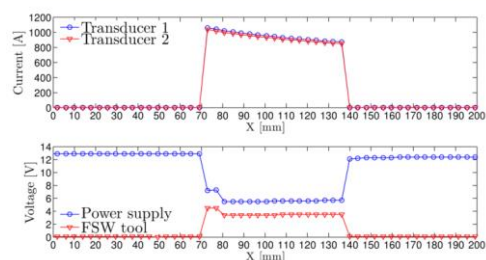


AA6082-T6

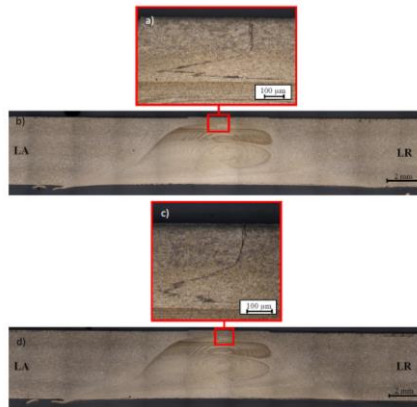
FSW along rolling direction

210 mm x 103 mm

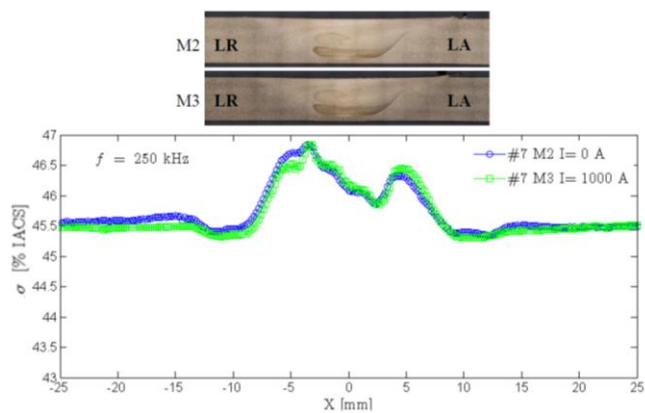
✓ Thickness: 4 mm



Joints and Electrical Parameters Conductive Inner Shaft Made of Stainless Steel AISI 316L



Joints and Electrical Parameters Conductive Inner Shaft Made of Stainless Steel AISI 316L



Conclusions

- ↳ The innovations implemented proved to be a feasible method for significantly reducing the lack of penetration
- ↳ The FSW tool developed with conductive inner shaft made of copper is efficient but the tip of the conductive inner shaft undergoes significant wear
- ↳ The new FSW tool developed with conductive inner shaft made of stainless steel is not efficient concerning the reduction of the LOP
- ↳ The best conditions of FSW assisted by Joule effect resulted in a decrease of hardness in the HAZ in the vicinity of the root surface