Santos Vilaca da Silva, Pedro

My Innovations stirred by wunderbar Dos Santos

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Honory symposium on the occation of Dr. Jorge dos Santos' 65th birthday

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There are 2 angels in my professional life…
Today is about to Honour one of them…

Why was I sent all the way from Rio de Janeiro... to take care of this guy's psychosis?

If he went to look for me in Cranfield and Tesperhude...

I am afraid, there is no place in this world to hide from him...

Wunderbar… Jorge dos Santos

A bit of (pre-)historic scope

Scenario: 1995-1997 (on my way… to Jorge dos Santos)

- 1995 - Lecturer and MSc student at IST (Technical University of Lisbon, Portugal) under supervision of Prof. Luisa Coutinho, on: “Numerical Analysis of the Structural Mismatch Effect on Crack Propagation in Welded Structures”

- 1996 – MSc thesis developed @ Cranfield University (UK) under co-supervision of John Norrish and John Spurrier


- By August 1997 start academic career as Assistant at Mechanical Engineering Department of IST (Technical University of Lisbon, Portugal)

- Start PhD under supervision of Prof. Luisa Coutinho, on: “Modelling of Laser Welding of Metals”
…it all Started in 1997

First visit… to Jorge to Santos, by November 1997

- First Visit to GKSS Jorge dos Santos R&D group at promoted by Luisa Coutinho
- Scope: modelling of laser welding was big at GKSS
  - Main objective: To develop contacts on "Modelling of laser welding of metals"
- Funding support: Calibrate and start XRD equipment for residual stress measurement, complementing the existent ND – Operation/presentation to visitors
- Most impressive memories…
  - The complex physics of laser beam and weld pool was also a challenge at GKSS
  - Amazing… Geesthacht Underwater Simulation Facility showing that divers could work safely and effectively at a depth of 600 meters
  - Amazing… Friction based processes by Friction Hydro Pillar and Friction Stir Welding concept with installation of the first Tricept robot
  - The mushrooms in the forest were amazingly big… I understood better the Greenpeace demonstrations at the nearby nuclear power plant
...it all started in 1997

Back in Portugal:

Laser Physics versus FSW Physics
● The FSW process is Mechanical Engineering from A to Z

Inspired by the genuine enthusiasm and light in Jorge’s eyes

I took the key decision:
● Modify the R&D focus from Laser to FSW

...and considering the technological conditions in Germany versus Portugal to implement the FSW...

1998 – Second visit to kick-off the plan of action:

✓ With the bless and authorization by Luísa and Jorge, a new plan of action was born:

1. Modelling @ IST, Portugal + Experimental Validation @ GKSS, Germany
2. Setup and Launch the FSW process in Portugal

✓ After 1998, and by the hand of Jorge dos Santos... I got:

😊...guided tour at the 51st IIW, Hamburg, September 1998 (hosted by DVS)... probably the first Young Professionals/Students action at IIW annual meetings

😊...shared participation @ 1st “Friction Stir Welding and Processing” TMS symposium, Indianapolis, USA, 2001, by Mahoney, Mishra, et al.

😊...the vision of the future of Friction Stir Based Processes at the IIW and in the society was consolidated
I went for it without looking back…
and Jorge surely guided me to the end… of my PhD

April 2003

FSW process in Portugal

to 2013… many applications, covering wide range of technology readiness levels
FSW process in Portugal
electrical transformers bobbin's - SIEMENS
The modelling of FSW

Challenge: to deal with complex thermal/metalurgical/mechanical coupled nature of FSW phenomena and material model dependence on \( (T; \varepsilon) \)

1st Approach: Numerical Modelling Approach
Integration CSM / CFD
- Elastic-Plastic: analysis of the pieces removed from tool HAZ and Base Material
- Viscous-Plastic: analysis with high tool speed
- Fluid Dynamics Approach (e.g. Fluent)
- Structural Mechanics Approach (e.g. Abaqus)

Results
- Residual Stress Field
- Residual Deformation
- Thermal History of the 5th

Computational Solid Mechanics (CSM)
- Finite Element Method
- Implicit Integration Scheme
- Thermomechanical Coupled Analysis
- Lagrangian Analysis
- Lambda Analysis
- Viscous-Plastic Material (Dinero-Hollomon)
- Solid Fluid Contact Model

The modelling of FSW

2nd Approach...
FSW Thermal Analytical Modelling
- Analytical/Empirical Formulations
- Experimental Temperature Measurements
- Heat Power \( P_{\text{heat}} \)
- FSW Parameters

\[ P_{\text{heat}} = \frac{\Omega}{V} \quad \text{and} \quad P_{\text{heat}} = \frac{100\%}{\text{input power}} \]

ISTIR Code “Inverse Engineering Approach”

Sample of Correlations with ISTIR Code
- Bobbin-tool (self-feeding)
- AA2024-T31 (T31-H111)
- Set of correlations: AA2024-T31 (thermo-mechanics)
- Weld interface (khaki)
- Thermal cycle (green)
- Stress cycle (red)
- Temperature (blue)
- Conventional tool: \( P_{\text{heat}} = 250W \)
The modelling of FSW

Participation at the “FSW Flow Visualisation and Modelling Seminar at GKSS” on February 2003 (1st), February 2005 (2nd), April 2008 (3rd)

Cooperative (still pinging) publications, e.g.:

  - 39 Citations (google scholar)

- P Vilaça, L Quintino, J dos Santos, “iSTIR – Analytical thermal model for friction stir welding”, Materials Processing Technology, 169(3). 2005
  - 77 Citations (google scholar)

Learning is still delivering the most up-to-date solutions:

Development of the FSW tool used for sealing copper canisters in disposal of spent nuclear fuel

Comparison Results: Simulation to Simulation
Flow Patterns: Vertical (v) Velocity
- Velocity magnitude shows the amount of material flow, but direction is also critical
- Vertical velocity (v) is the critical, non-reversable, material flow direction

Probe B: Original vs Real
Others in my IST R&D team touched by the Jorge’s Magic

Telmo Santos (NDT of FSW)
João Gandra (FSP and FSurfacing)
Catarina Vidal (FSChanneling)

NDT of FSW

- The transfer of FSW to high quality demanding industries depends on the level of reliability of the weld joins
- However, the actual NDT reliability in characterizing and sizing the typical FSW defects still remains a challenge
- Thus, the development of reliable NDT techniques is fundamental
The application of the Defect Index to the 3 defect types clearly show a proportionality between them. This result is confirmed by different frequencies.
Other applications of eddy current to FSW assessment of conductivity

Case Study: Scanning of conductivity in cross-section of FSW of AA7075 plate (cont.)

Planar spiral probe with 20 windings

Friction Stir Processing

Results for:
FS Processing in-Volume

Embedding of SiC particles for FGM

Overlap Ratio = OR

Smooth concave shoulder for better superficial appearance
Friction Surfacing… applications

Production of Functionally Graded Materials (FGM)

Friction Surfacing… with secondary flash formation

Step 2

Step 3

Coating layer with Primary Flash Formation (PFF)

Coating layer with Secondary Flash Formation (SFF)

CAUTION

 далее, с целью представления в интересах конечного пользователя, нет необходимости в визуализации и описании данных, поскольку они не касаются темы машиностроения или материалов.

Если требуется, то можно вернуться к предыдущему состоянию страницы.
Friction Surfacing… with secondary flash formation

311 HV
254 HV
215 HV
270 HV

Aalto University
School of Engineering
Department of Mechanical Engineering
Engineering Materials

New Friction Based Technique
Friction Flash to Tube (F2T) – Aaltube @ Aalto, Finland

AASXXX
AISI 420 (martensiticSS)
Grade 2 Titanium

Aalto University
School of Engineering
Department of Mechanical Engineering
Engineering Materials
New Friction Stir Based Technique
Hybrid Channelling: new milestone in FSC domain

Tailor-made Channels...
...with self-Detachable flash
...can have any path
...can have constant or variable shape along the path
...can be produced at different depths

Friction Stir Based Technique
Hybrid Channelling: new milestone in FSC domain
Friction Stir Based Technique
Hybrid Channelling: new milestone in FSC domain

New Friction Stir Based Technique
Through Hole Extruded Welding (THEW)

- New manufacturing technique to produce hybrid multilayer structures based on joining Metal to Polymer based components
- Special oriented for load bearing thick structural components

**Variants:**
- Spot or Multi-spot
- Slot (continuous linear or circular)

**Joining mechanisms:**
- Mechanical interlocking
- Multi-directional joining
- Adhesion

**Asymmetric Joint**
New Friction Stir Based Technique
Through Hole Extruded Welding (THEW)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Geometry</th>
<th>Diameter [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thickness of AA Nook</td>
<td>1.892</td>
</tr>
<tr>
<td>2</td>
<td>Penetration of AA Nook to Polymer</td>
<td>3.482</td>
</tr>
<tr>
<td>3</td>
<td>AA Coding</td>
<td>12.714</td>
</tr>
<tr>
<td>4</td>
<td>Open Thread AA Nook</td>
<td>3.416</td>
</tr>
</tbody>
</table>

Joint hook thickness: 
≈ 1.5 mm

FSW of Steel at Aalto
new control of FSW of steels

...via Monitoring Magnetic Permeability of stirred zone

Phase transformation
\[ \alpha \rightarrow \gamma \]

Magnetic permeability transformation
\[ \Delta \mu \] (\( T_{\alpha} < T_{FSW} < T_{\gamma} \))

FSW \Rightarrow Weld zone processed
@ intercritical \( \Delta \text{temperature} \)

- Preventing full austenitization
  - Best overall properties?
- Low Heat Input:
  - Avoid loss of toughness at HAZ
  - Retain the good balance: strength versus toughness
  - Low residual deformation

And here’s to you… Mr. Wayne Thomas
with Jorge, I also learned to respect… the man behind the FSW

Bolton University
Wayne Thomas, PhD, June 2009

Contribution for the IIW via Commission III
committed service as Chair of CIII-B

Note:
Intermediate Meeting C-III
6th – 7th March 2019
@ GM R&D Centre, USA
CONCLUSION

Cara ... !
After all these years, putting up with this hopeless case,
I need to retire to overcome my own post traumatic stress