Detailed Multiphysics Modeling of the Friction Stir Welding Process
(DEEPWELD, FP6, 04/2005-04/2008)

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The Friction Stir Welding process (FSW)

- Hard cylindrical shouldered tool: rotated and slowly plunged into the joint line between two workpieces butted together

- Frictional & Stir generate heat at the joint: workpieces soften without reaching the melting point (solid-state process)

- The plasticised material is transferred from the leading edge to the trailing edge of the tool probe (stirring effect)
DEEPWELD Objective (2005-2008)

Partners: CENAERO, EADS CCR, SONACA, IS, UCL, ENSMSE, QUB, CIMNE, QUANTECH

- Operating parameters
  - Advancing speed
  - Rotating speed
  - Forging load
  - Tilt angle
  - Clamping & Tooling
  - Cooling device

- Workpieces data
  - Constitutive law
  - Friction law
  - Metallurgical state
  - Thickness/geometry

Output results
- Residual stresses
- Distorsion
- Joint behavior
- Metallurgical state
- Structural response

MORFEO code (simulation)
Multi-physics & Multi-scale modelling of the FSW process
Numerical modelling of the FSW

**Operating parameters:**
- rotating speed
- advancing speed
- pressure applied
- plunged probe design
- clamped parts

**Consequences:**
- friction
- large strains
- large strain rates
- heating up
- viscous pool
- residual stresses
- distorsion

**Physical phenomena:**
- mechanical
- thermal
- fluid flow (stirring)
- metallurgy

Multi-physics modelling
The multi-physics approach (1)

Physical phenomena:
- fluid flow
- thermal
- mechanical
- metallurgy

Thermo-mechanical analysis:
- distortion prediction
- residual stresses prediction

Analysis data:
- heat source
- clamping & tooling device
- cooling device

Unknown:
Which heat source to apply?

⇒ Experiments and calibration

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The multi-physics approach (2)

Physical phenomena:
- fluid flow
- thermal
- mechanical
- metallurgy

Analysis data:
- shoulder & probe geometry
- speeds & pressure
- material viscous properties

Thermo-fluid flow analysis:
- shear stress at the shoulder
- strain rate & stress tensors
- powers of deformation & friction
⇒ no need of calibrated heat source

Thermo-Fluid flow calculation

Real heat source (Morfeo v1.0)

Fluid flow (Morfeo v1.0)
The multi-physics approach (3)

Physical phenomena:
- fluid flow
- thermal
- mechanical
- metallurgical

Thermo-metallo-fluid flow analysis:
- dynamic recrystallisation
- precipitation
- hardness calculation

Analysis data:
- temperature excursions
- strain excursions
- strain rate excursions

Thermo-Fluid flow (Morfeo v1.0)
The multi-physics approach in DEEPWELD

Physical phenomena:
- fluid flow
- thermal
- mechanical
- metallurgical

MULTI-PHYSICS approach
The multi-scale approach

GLOBAL MODEL:
Coarse mesh

LOCAL MODEL:
Very fine mesh

Mesh-size increases

LOCAL/GLOBAL approach
The local model - MORFEO

The meshed local FSW model:

Velocity field computed accurately:
The local model - MORFEO

Temperature computed accurately:

Temperature plotted along a section:
The local model - MORFEO

Tracer particles/strip along weld line:

(Morfeo v1.0)
The local model – experimental validation

Validation of MORFEO results with tracers’ flow observations:

Good agreement at the boundaries
The local model – MORFEO accelerated

Parallelisation:
From $1^{1/2}$ day to 4h30 of computation with 8 domains
The global model

Features of MORFEO:

- Staggered Thermo-Mechanical coupling
- Multi-body contact (workpiece + backing plate + tooling device)
- Moving Forging Load (welding velocity)
- Moving Heat Input (welding velocity): from the local model
- Conduction, Convection and Contact Conductivity
- Thermal dependancy of the mechanical properties
- Thermal dependency of the thermal properties
- Clamping, Release and Cooling Down

- Calculation of:
  - Distorsion
  - Residual stresses state
The global model using MORFEO

(Morfeo v1.0)
The global model using ABAQUS
The global model using SAMCEF
The local/global communication

*From:* MORFEO *(accurate thermo-fluid analysis)*

*To:* MORFEO *(thermo-mechanical analysis)*
  
or ABAQUS *(thermo-mechanical analysis)*
  
or SAMCEF *(thermo-mechanical analysis)*

*Via:* MPCCI *(Mesh-based Parallel Code Coupling Interface)*

*Transfer of:* the thermal energy produced during the FSW
The local and global meshes: overlapping
The local and global meshes: interpolation
The global model: temperature calculation
Conclusions

DEEPWELD brings the following innovations:

Innovation 1: Local/global approach for accurate and fast calculation
Innovation 2: Material flow study and influence on the metallurgy
Innovation 3: No experimentally calibrated heat flux
Innovation 4: Complex friction/constitutive laws
Innovation 5: Microstructure evolution
Innovation 6: Validation on real-life coupons representative of aeronautical applications
Innovation 7: Optimisation of welding parameters
Innovation 8: Optimisation of the probe geometry for better welding performances

MORFEO upgraded with the DEEPWELD project features for a multi-physics and multi-scale modeling of the FSW
More Info

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