Strategy for the simulation of the ITER Toroidal Field Coil Case welding distortion using Finite Element Method

FUSION FOR ENERGY

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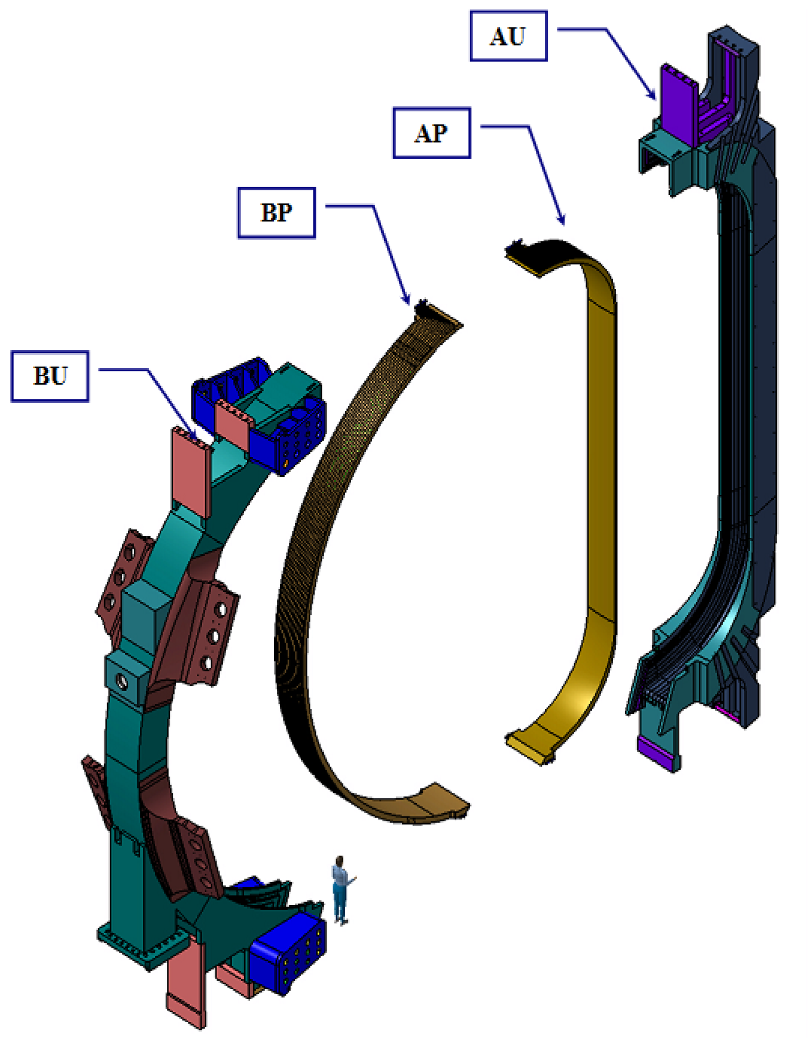
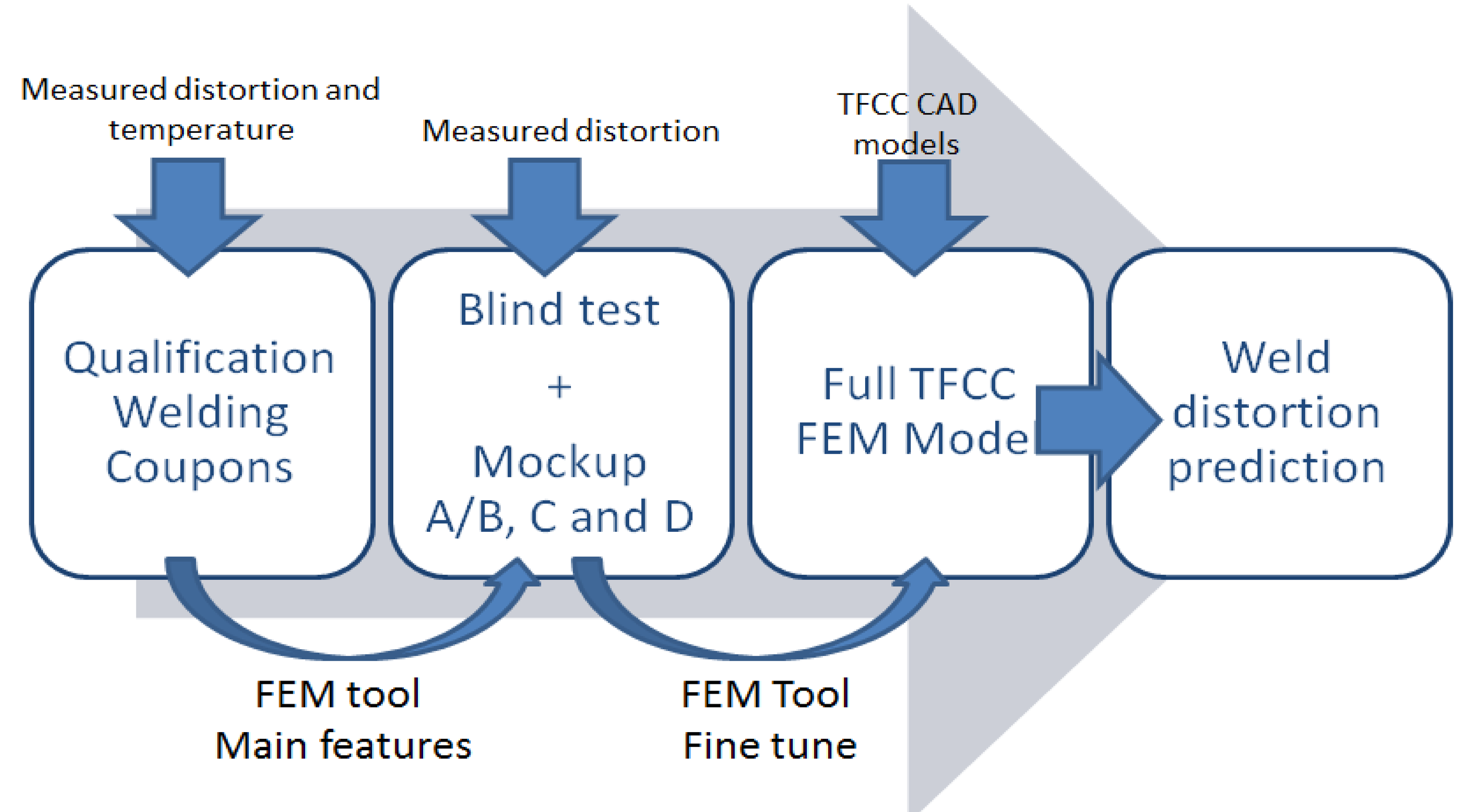
1. Introduction

- Toroidal Field Coils Cases (TFCC) are SS316LN structures, weighting about 150t and with wall thicknesses from 60 to 120mm.
- Displacement of the cases due to welding distortions should be as limited as possible in order to optimize over-metal strategy for tolerance requirements.
- Need for a strategy to assess welding distortions in efficient matter, considering industry production needs and times.
- Campaign was started consisting in real welding of TFCC-like structures in order to create a suitable FEM tool and feed it with experimental data.
- EnginSoft S.p.A was the developer of FEM models, SIMIC S.p.A was the responsible of welding processes and data acquisition, and Fusion for Energy was the contractual and technical supervisor.



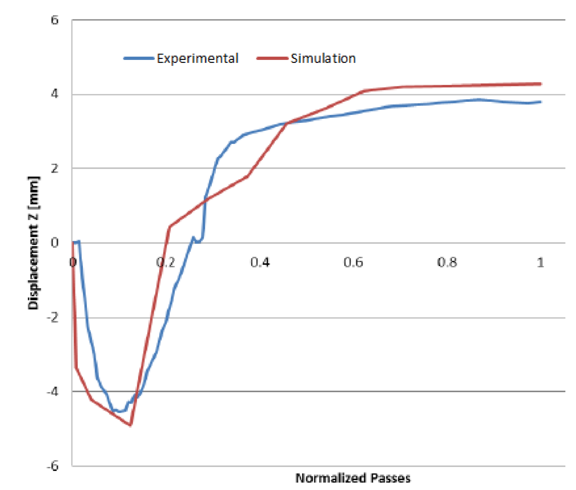
2. Methodology

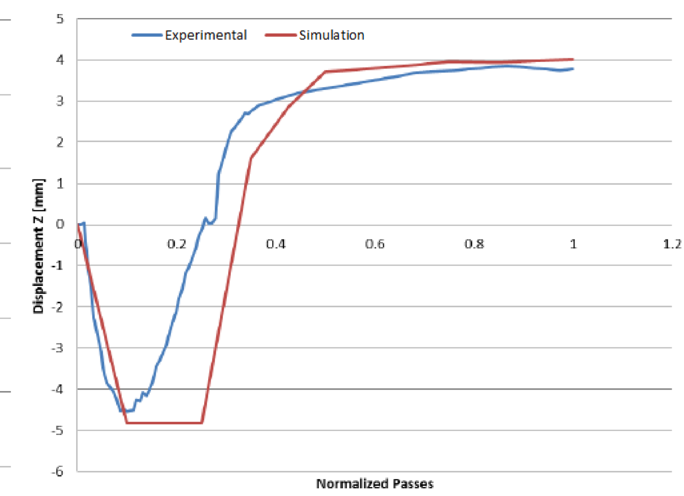
We planed a set of experimental welding exercises to build the FEM tool; First, welding qualification coupons were used to establish the main aspects of the model. Then, the welding structures increased complexity, being now scale 1:1 sections of the real TFCC . In this way the interaction of different welding passes and more complex geometries were tested and introduced in the FEM tool. With this, the FEM tool was ready to be used in the full TFCC geometry, in order to predict deformations of the real case.

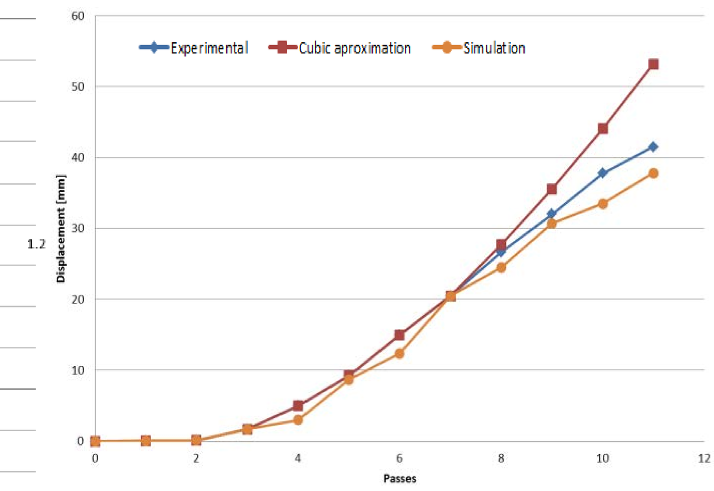


3. FEM model definition and calibration with Welding Coupons

- Simplification of the numerical problem by de-coupling the thermal-transient using a quasi-steady state analytical solution for a moving heat source (Rosenthal models).
- Mesh reduction via clustering weld passes maintaining as much as possible the real sequence in the material deposit of the real welding sequence.
- Use of techniques based in ANSYS technology of element 'birth' and 'death' to simulate material deposition, element activation to simulate welding material.
- All this numeric techniques were used to feed the FEM tool via a series of tuning parameters: cut-off temperature (temperature at which an element is activated), welding chord mesh size and coefficient of thermal expansion (CTE) of chord material.
- Extract of calibration steps are shown below: initial comparison of vertical displacement of coupon TIG1, same coupon comparison of results after tuning, and final comparison of the coupon used for blind test.

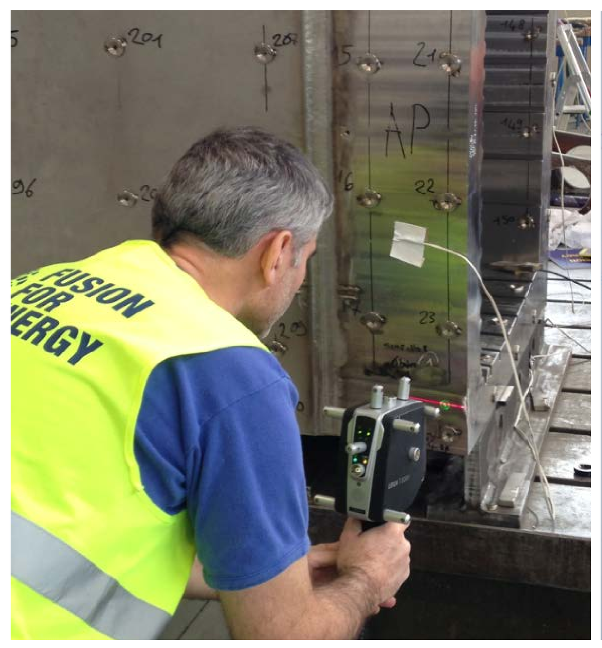


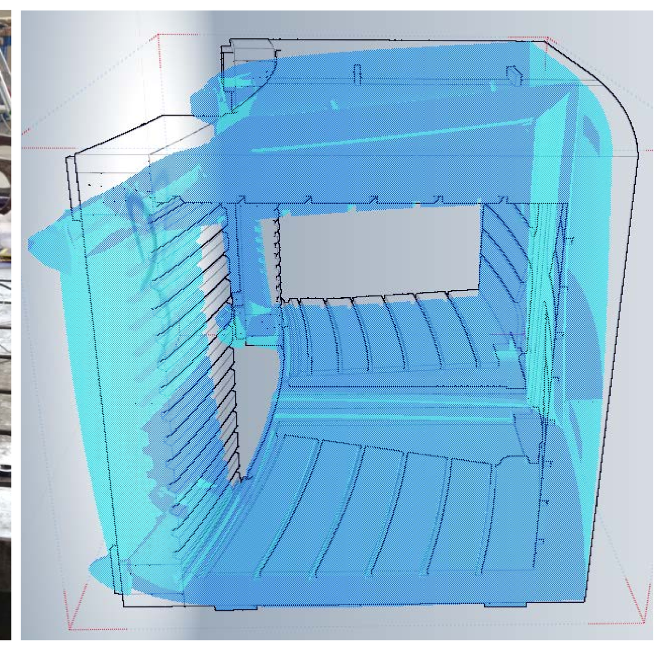


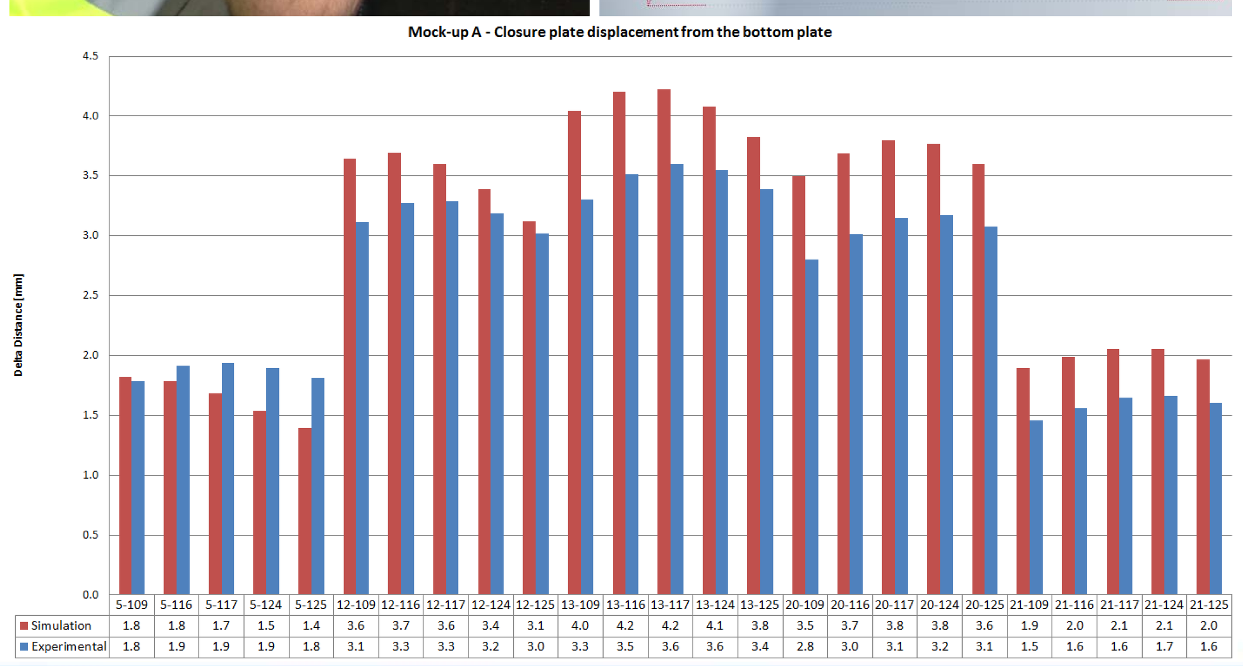


4. Full Scale Mock-ups activity

- Three full scale 1 meter long mock-ups - MU-A, MU-C, MU-D - were welded in SIMIC workshop, each process taking more than 1 month to complete.
- Basic comparison method: distance variation between control points in FEM model and real structures.
- For MU-D (below) laser scanning method provided a more direct tool to compare distortions of welded structures with deformed geometry from FEM.
- FEM tool optimization allowed to keep solution time of the model less than 1 week.
- Control point comparison was qualitatively coherent in all mock-ups. See MU-A example below were closure plate distance are plotted for experimental and simulation results.





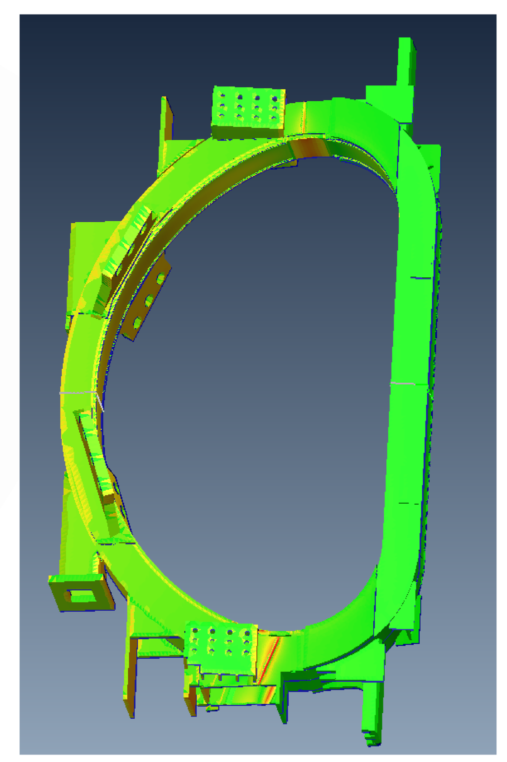


	5-109	5-116	5-117	5-124	5-125	12-109	12-116	12-117	12-124
Simulation	1.8	1.8	1.7	1.5	1.4	3.6	3.7	3.6	3.4
Experimental	1.8	1.9	1.9	1.9	1.8	3.1	3.3	3.3	3.2

	12-125	13-109	13-116	13-117	13-124	13-125	20-109	20-116
Simulation	3.1	4.0	4.2	4.2	4.1	3.8	3.5	3.7
Experimental	3.0	3.3	3.5	3.6	3.6	3.4	2.8	3.0

	20-117	20-124	20-125	21-109	21-116	21-117	21-124	21-125
Simulation	3.8	3.8	3.6	1.9	2.0	2.1	2.1	2.0
Experimental	3.1	3.2	3.1	1.5	1.6	1.6	1.7	1.6

5. Complete TFCC model activity



- The TFCC full model includes all the steps of the real welding sequence, tack weld, butt welding, poloidal welding and splice plates.
- It uses all the previous parameters defined and tuned with the coupons and mock-ups experimental and simulation activities.
- Boundary conditions reproduce true constrains of the assembly rig, allowing the displacements of the support with minimum reaction forces.
- We succeeded to reach a low value of DOF using shell elements where possible, thanks to a benchmarking activity performed with the mock-ups models.
- The model runs in ~2 days, which reduces previous solving times which was ~1 week.
- First results of TFCC model simulations are obtained; main global distortion predicted is an approach of AU-BU structures. Out of plane distortion is foreseen to be much more limited.
- Full post-processing and treatment of the control points displacement and interface control is currently ongoing.

6. Conclusions and future activities

- FEM tool developed predicts qualitatively the global distortion of the TFCC-like structures.
- Calibration and validation activities require dedicated tests to be easily replicated with FEM models.
- Adequate data acquisition methods and comparison processes with experimental models are essential for proper FEM tool construction and validation.
- Method for full TFCC model data comparison with real welding process will be developed for the final over-metal and tolerances assessment. See images of control points tracking in TFCC interface areas.