BP8.64:

IGNITOR Plasma Chamber Assembly Procedure and Welding Processes* G. TOSELLI, G BARBIERI, B. CARMIGNANI, G. CELENTANO, F. COGNINI, A. CUCCHIARO, U. DE MAIO, A. IERINO, T. MINGHETTI, G. PANZANI, S. SANGIORGI, M. TIMPANARO, D. TRESTINI, D. VISPARELLI, ENEA, Italy, B. COPPI, MIT

— The appropriate welding techniques to be adopted for the assembly sequences of the 12 sectors of the Plasma Chamber, are described. The last welds, joining two assembled 180° sectors of the plasma chamber, need to be carried out automatically, at the inside of the Chamber, guided and controlled by the remote handeling system. The deformations and the displacements due to these welds have to be very limited in order to comply with the design geometry of the closed torus and its functions (e.g. support of the First Wall structure). Numerical simulation of the relevant welding processes have been carried out. Two different welding techniques have been chosen.
–Laser welding for the junction of 4 mm of the thickness of adjacent sectors of the plasma chamber
–TIG-NG welding with filler material for the remaining thickness
Experimental tests and corresponding simulations have been made, for both of these welding processes, on suitable samples which reproduce some aspects and geometrical characteristics of the chamber sectors. The most significant results obtained are described and discussed.

*Sponsored in part by ENEA of Italy and by the U.S. D.O.E.

Bull. Am. Phys. Soc. **52(16)**, 45 (2007)

Numerical Simulation Tool for Setting up Welding Processes

Applications towards IGNITOR Plasma Chamber Assembly

G.Toselli (**), G.Barbieri (*), B.Carmignani (**), G.Celentano (***), F.Cognini (*), A.Cucchiaro (***), U.De Maio (****), A.Ierinò (*****), T.Minghetti (****) , G.Panzani (****), S.Sangiorgi (****), M.Timpanaro (****), D.Trestini (****), D.Visparelli (**), M. Bonifazio (******), B. Coppi (*******)

(*) ENEA - FIM-MATTEC (Via Anguillarese, 301-00060 - S. Maria di Galeria-Rm)
(**) ENEA - FIM-CAMO (Via Martiri di Monte Sole, 4 – 40129 Bologna)
(***) ENEA - FPN-FUSTEC (Via E. Fermi, 45 – 00044 Frascati-Rm)
(****) ENEA – FIM- MATING (Via Ravegnana, 186 – 48018 Faenza-Ra)
(*****) Università degli Studi della Calabria – Fac. Ing. dei Materiali
(******) Università degli Studi di Palermo- Fac. Ing. Meccanica
(*******) MIT – Boston (Ma – USA)

1

The numerical simulation of an industrial process (in our case welding process)

an useful tool, for the preliminary knowledge, pre-analysis, design, prototype construction and also for the production.

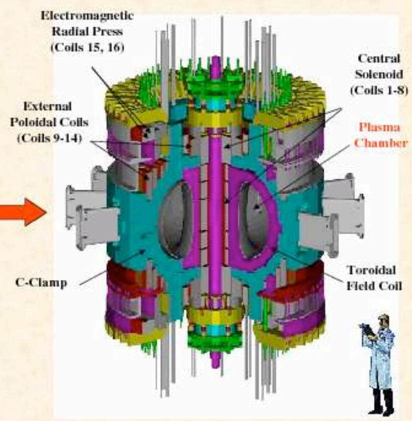
Welding Processes of interest Ł

- *Laser welding*
- *TIG-NG welding with filler material*

for

2

the Assembly of the Plasma Chamber in the Thermonuclear Fusion Reactor IGNITOR

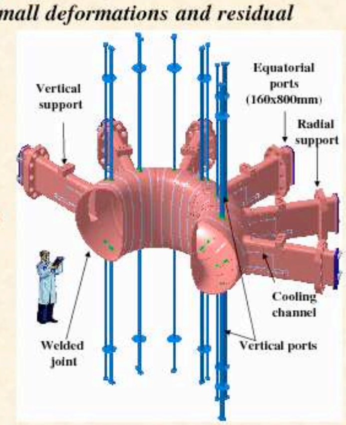


3

The Laser welding technique, as known, is used in order to assure small displacements, small deformations and residual stresses in very limited zones

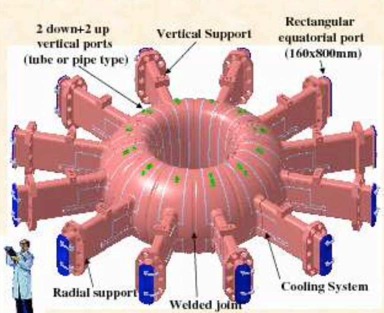
The TIG-NG welding is used when the thickness of the pieces to be welded is large

When the welding must be used in very critical situations, due to the particular geometries of the pieces to be welded (as in the case of the IGNITOR Plasma Chamber Assembly), to know a priori the phenomenon evolution and the values of the physical quantities of interest (displacements, strains and residual stresses) becomes very important and necessary



4

Plasma Chamber Ł *constituted by 12 equal sectors of nickel-chromium alloy, INCONEL 625, with a section of "D" shape, to be be joined by welds in such a way to form a closed torus*



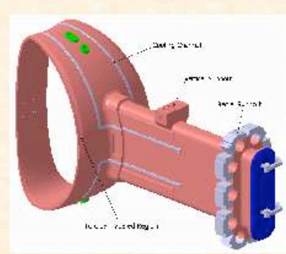
Welds to be carried out from the Chamber inside, utilizing suitable welding tools externally controlled

Actual choice :

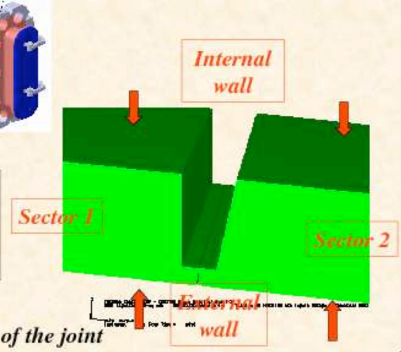
** Laser welding for the first 4 mm of the joint along the thickness*

** TIG-NG welding with filler material for the remaining thickness of 22 mm*

5



Geometry of each of the sectors to be together welded



Minimum chamfer width 8 mm
Maximum chamfer width 12 mm

Detail of the joint

6

After some preliminary calculations which made reference to simple test models in order to single out the best numerical methodologies to be used,

two models, experimentally realized at ENEA laboratories, significant as concerns their geometrical dimensions compared with the ones of Plasma Chamber Sectors, have been considered just in order to compare experimental measures and numerical results.

The numerical simulations have been performed solving uncoupled thermo-mechanical calculations by the use of FEM non-linear thermo-structural analysis code, ABAQUS/S code, generally on PC machines.

7

This means that for each simulation of a welding process

firstly, thermal calculation is executed in order to determine the temperature distributions due to the welding (Laser or TIG-NG) source and its movement

subsequently, structural calculation in order to determine the mechanical response of the welded pieces as consequence of the calculated temperature distributions

8

MF1 Model

Experimental Test only for TIG-NG welding with filler material

MF2 Model

Experimental Test for both Laser and TIG-NG welding techniques

9

Organization of the simulations

1. *In order to optimize the calculations:*

   very fine mesh discretization in the central zones, the most interested zones by the (Laser or TIG) source movement

   gradually coarser mesh discretization in the external zones

2. *In each simulation:*

   firstly, the heating phase is simulated, that is the source (Laser or TIG) application and movement

   subsequently, the cooling phase is simulated up to reach the room temperature

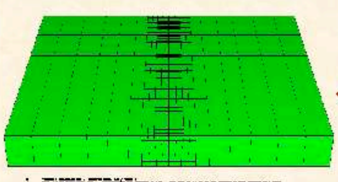
3. *Sources represented by:*

   in the case of Laser welding Ł volume sources and/or surface sources suitably distributed along the thickness of the volume/area interested by the Laser beam

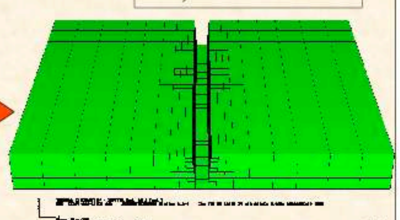
   In the case of TIG-NG welding Ł suitable temperature distributions on the surfaces of the elements representing the drops of filler material

10

MF1 Model : Numerical simulation only for TIG-NG welding process (both pieces externally constrained)

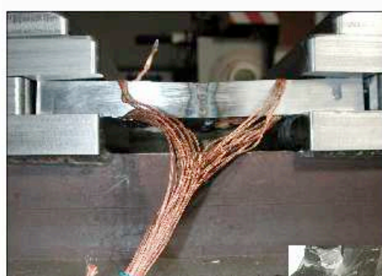


Mesh schematization and discretization adopted for the numerical simulation considering the filler material (general view)



Mesh schematization and discretization adopted for the numerical simulation as initial geometry (general view)

11



MF1 Model

Experimental Test only for TIG-NG welding Ł 15 passes for 15 layers in the chamfer

Welding executed by hand with medium velocity of 7.3 cm/min

Final result with the constrained welded piece, situation of interest for Plasma Chamber Assembly

12

MF1 Model

Numerical simulaltion of TIG-NG welding Ł

15 passes for 15 layers in the chamfer

TIG source velocity adopted Ł 8.6 cm/min

Final result with the constrained welded piece

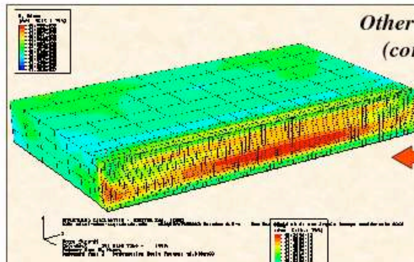
Maximum displacement in z direction

Ł experimental = 2.0 mm
calculated = 2.4 mm

Maximum fletch in z direction

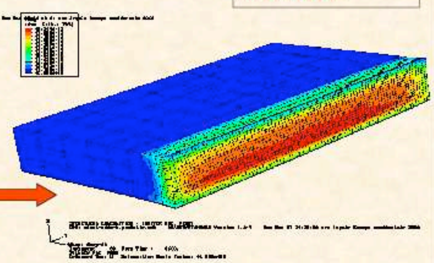
Ł experimental $\alpha = 1.64°$
calculated $\alpha = 1.13°$

Other numerical results (constrained piece)



Von Mises stress distributions

Maximum value = 863.8 MPa



Equivalent plastic strain distributions

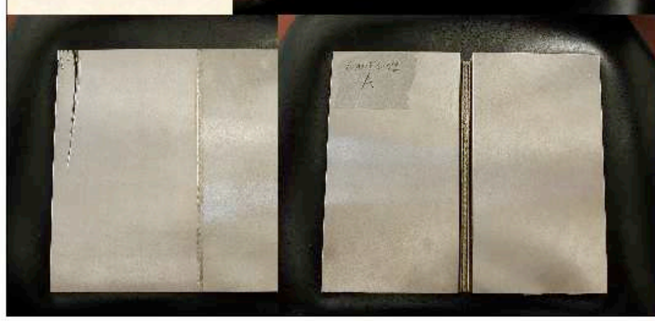
Maximum value = 21.4 %

MF2 Model

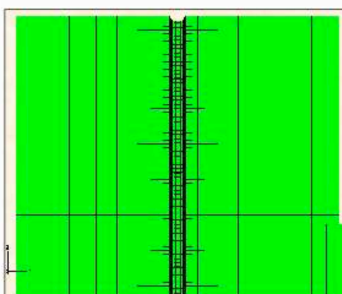
(piece welded initially by Laser with no gap and then by TIG-NG)

Laser Nd-YAG with 2 kW continuum power source.
Beam diameter = 0.45 mm.
Beam velocity = 8.33 mm/sec.

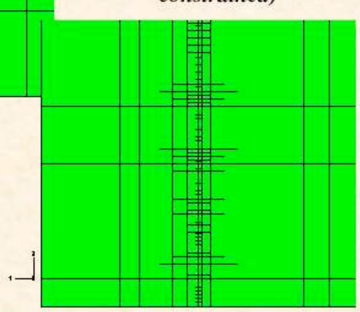
Final experimental result



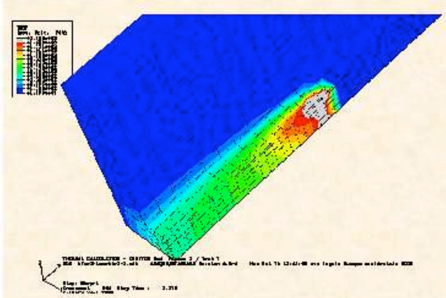
MF2 Model

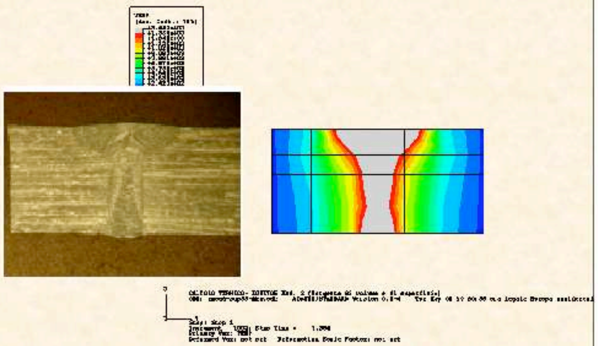


Numerical simulation for initial Laser welding process (no gap and both pieces externally constrained)



Mesh schematization and discretization adopted as initial geometry (general view on upper and lower parts)



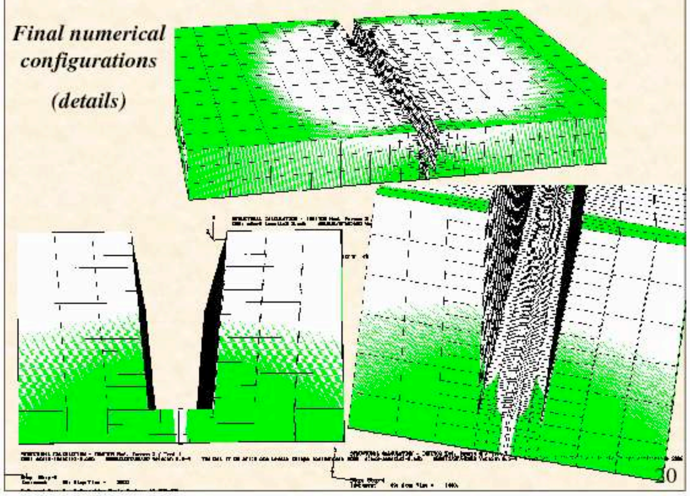


Comparison of the experimental keyhole form with its numerical representation

19

Final numerical configurations

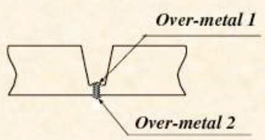
(details)



20

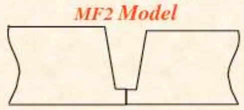
Experimental displacements

Over-metal of welded central zone

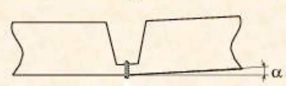


Over-metal 1:
0.10 mm (at a boundary)
0.30 mm ÷ 0.40 mm (on the remaining central welded zone)
Over-metal 2:
0.10 mm ÷ 0.30 mm

Schematization of MF2 Model

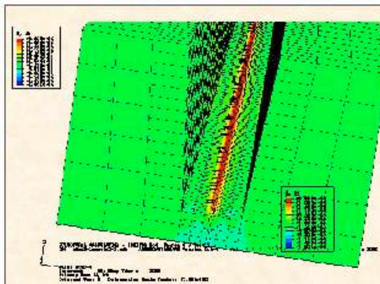


Final fletch

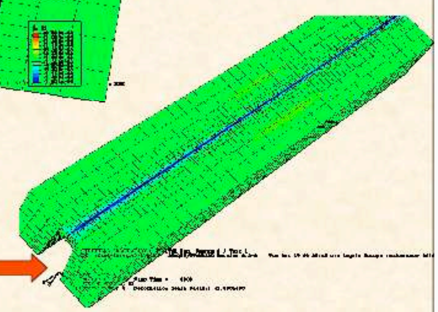


Angular displacement $\alpha = 8'$

21



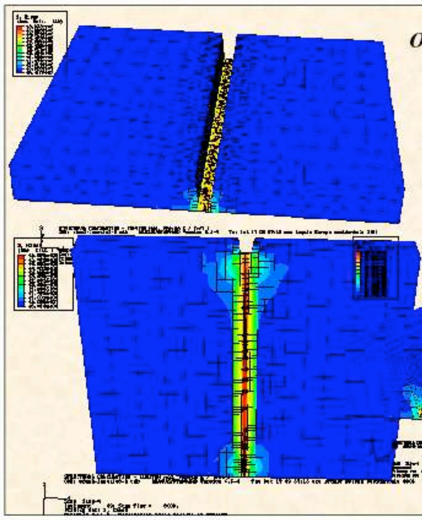
Numerical displacements



Maximum value on the upper part ± 0.22 mm

Maximum value on the lower part ± 0.18 mm

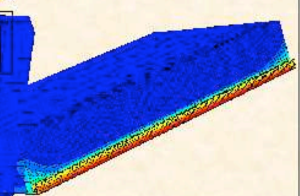
22



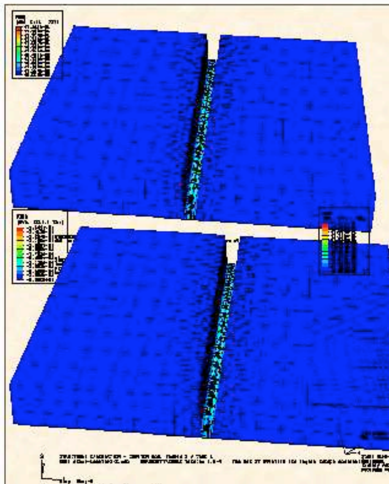
Other numerical results

Von Mises stress distributions

Maximum value = 597.5 MPa

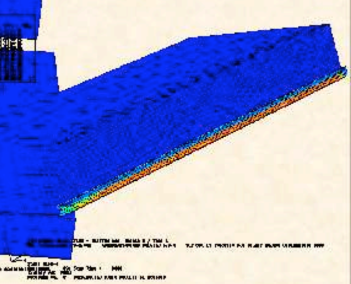


23



Equivalent plastic strain distributions

Maximum value = 15.4 %



24

MF2 Model

Subsequent TIG-NG welding Ł 15 passes for 15 layers in the chamfer

Initial configuration

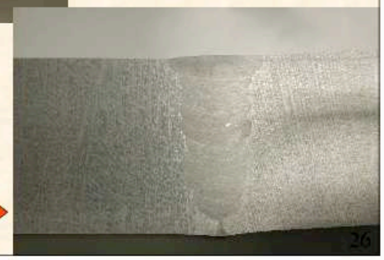
Welding executed by hand with medium velocity of 12 cm/min

Final result with the constrained welded piece, situation of interest for Plasma Chamber Assembly

25

MF2 final configuration: welded zone shape at an internal part along the thickness

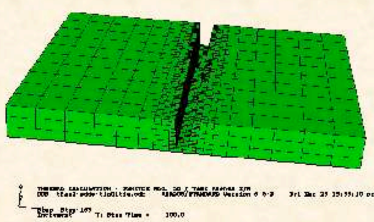
MF2 final configuration: welded zone shape at an external side along the thickness (where each TIG-NG welding pass ended)



26

Numerically, after the simulation of the Laser welding process, in order to perform the simulation of the subsequent TIG-NG welding, it has been necessary to pass from the very fine mesh in the central model zones to a more suitable coarse mesh

By a re-mapping the new adopted mesh has been chosen equal to the one used in MF1 Model, that is:



27

MF2 Model

Numerical simualtion of TIG-NG welding Ł

15 passes for 15 layers in the chamfer

TIG source velocity adopted Ł 12 cm/min (as in the experience)

Final result with the constrained welded piece

Maximum displacement in z direction

Ł experimental = 2.55 mm

calculated = 2.17 mm

Maximum restrictions in x direction

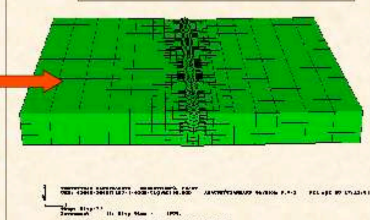
Ł experimental = 2.0 - 2.3 mm

calculated = 1.8 – 2.0 mm

Maximum fletch in z direction Ł

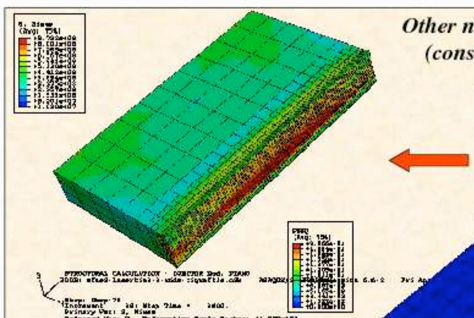
experimental α = 1.23°

calculated α = 1.04°



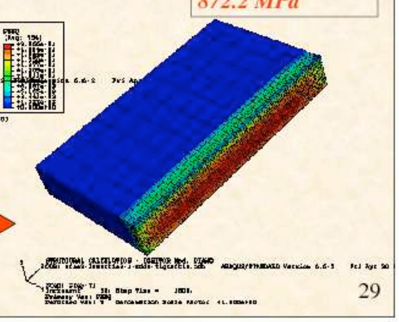
28

Other numerical results (constrained piece)



Von Mises stress distributions

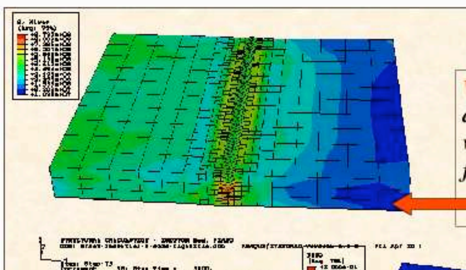
Maximum value = 872.2 MPa



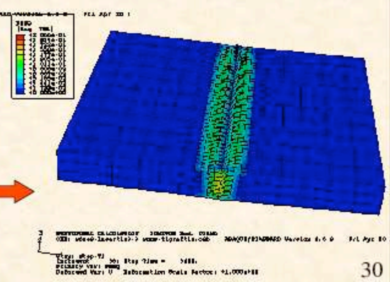
Equivalent plastic strain distributions

Maximum value = 21.4 %

29



Von Mises stress distributions on the whole model (view from upper part)



Equivalent plastic strain distributions on the whole model (view from upper part)

30

Comparisons of the results obtained for two physical quantities in the numerical simulations of MF1 and MF2 models , as concerns TIG-Ng welding

	MF1 (Calc - v = 8.6 cm/min)	MF2 (Calc - v = 12 cm/min)	MF2 (Calc - v = 8.6 cm/min)
Max. residual von Mises	863.8 MPa	872.2 MPa	862.1MPa
Max. final equiv. plastic strains	21.44%	20.66%	21.23%

CONCLUSIONS

A sufficiently accurate numerical methodology has been singled out and tested for the simulation of both Laser and TIG-NG welding processes

The obtained numerical results compared with the made experiences are generally underestimated; nonetheless, this underestimation is sufficiently small; in part it depends on:

- ***the less rigid boundary mechanical constraints in the experiences compared with the ones adopted in the corresponding numerical simulations***
- ***the lack of knowledge of material properties and mechanical behaviour at the high temperatures, after 800 -1000°C for the numerical calculations and the not automatic execution of TIG-NG welding for the experience.***

However, the numerical displacements obtained, in particular numerical restrictions along the direction orthogonal to the welding direction, are nearer (in some cases only lightly greater), also respect to the corresponding experimental values, to the limit imposed by the project people of IGNITOR Plasma Chamber, that is 2.0 mm. Experimental researches are still needed.

Finally, from the comparison of the final results of MF1 and MF2 Models and from the last table one can note an important result, that is:

- ***the effects of the initial Laser welding may be considered negligible respect to the ones due to the subsequent TIG-NG welds;***
- ***the velocity of the source movement in TIG-NG welding may influence the mechanical response***