Fatigue Lifetime and Power Handling Capability of Actively Cooled Plasma Facing Components for ITER Divertor

Presented by M. Missirlian

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Outline

- Context
- Main Features of Tested Components
- Testing Procedure / Aim
- Qualification of Manufacturing
- Damage Valuation after Thermal Fatigue Testing
- Summary & Conclusion
Outline

- **Context**

- **Main Features of Tested Components**

- **Testing Procedure / Aim**

- **Qualification of Manufacturing**

- **Damage Valuation after Thermal Fatigue Testing**

- **Summary & Conclusion**
ITER REQUIREMENT *(normal operation)*

- **Phase 1: “Mixed CFC / W”**
  - **Target** *(strike-point region) / CFC armour*:
    - $10 \text{ MW/m}^2$ steady state, 3000 pulses;
    - $20 \text{ MW/m}^2$ during 10 seconds, 300 pulses
  - **Target** *(baffle region) / W armour*:
    - $5 \text{ MW/m}^2$ steady state, 3000 pulses
    - $10 \text{ MW/m}^2$ during 2 seconds, 300 pulses

- **Phase 2: “Full W”**
  - $W$ up to $20 \text{ MW/m}^2$ in steady state!

**Next (near-term) Step**

- Qualification of different grades CFC/W (Phase 1)
- Minimize the manufacturing risk/cost during the series production (Phase 1)
  - Develop and qualify a *(reliable)* “Repairing process”
- Assessment of **consolidated technology CFC/W** (Phase 1 & 2)
  - Manufacturing quality/reproducibility;
  - Performance under thermal fatigue *(Strike-point region)*
- Investigation about combined effects (Phase 1 & 2)
  - Stationary Heat Loads + Transient Elms + Neutron Irradiation
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Main Features of Tested Components (1/2)

**CFC or W Components**
*(small-scale)*

- **CFC armour**
  - ~100 mm
  - PLANSEE

- **W armour**
  - ~90 mm
  - ANSALDO

- **8 components Plansee**
- **8 components Ansaldo**

**Vertical Target Prototypes**
*(medium scale)*

- **CFC**
  - ~300 mm
  - PLANSEE

- **W**
  - ~90 mm
  - ANSALDO

- **2 components Plansee**
- **1 component Ansaldo**

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**ITER GEOMETRY**

- **19 Components** (~70 CFC and ~95 W monoblock tiles)
- **12 CFC/W ‘repaired’ tiles** distributed out 11 components

Additional step of bonding for repairing process
Main Features of Tested Components (2/2)

Materials and Armour to Heat sink bonding Technology

- **CFC**
  - **Plansee**
    - SNECMA NB41
  - **Ansaldo**
    - SNECMA NB41 or NB31

- **TUNGSTEN**
  - **Plansee**
    - Pure W (rod)
  - **Ansaldo**
    - Pure W (sheet plate)

- **AMC**
  - Active Metal Casting
- **PBC**
  - Pre-Brazed Casting
- **HIP**
  - Hot Isostatic Pressing
- **HRP**
  - Hot Radial Pressing

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**Testing Procedure**

- **Pre-examination:** Visual and IR thermography
  - (SATIR Facility, Cadarache)

- **FE200 Facility (Le Creusot, France)**
  - Initial thermal mapping at 5 MW/m$^2$
  - Thermal Cycling: up to 20 MW/m$^2$
  - Final thermal mapping at 5 MW/m$^2$

- **Post-examination:** Visual and IR thermography
  - (SATIR Facility, Cadarache)

**Aim**

- **‘Monoblock’ Concept (CFC/W armour)**
  - Recent/Consolidated Technologies
  - Repairing process (series production)

- **Qualification of Manufacturing**

- **Assessment of Fatigue Lifetime**

- **Damage valuation after Thermal Fatigue**

- **Metallographic (Post-mortem) examination**
Control of Heat Transfer Capability of PFCs by Integrated NDT

(SATIR: Infra Red Acquisition and Data Processing Device)

- Principle: Infra-Red transient monitoring during hot/cold (100°C/5°C) water shock: Low heat transfer capability is detected by a slower temperature surface response

- Output of the SATIR Control: Cartography of quantitative criteria DTref_max
  - Inspection of each face (front, right, left) of each monoblock tile of each component!
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Qualification of CFC armoured components

**SATIR Pre-Examination for ‘Not-repaired’ / ‘Repaired’ Components (1/3)**

<table>
<thead>
<tr>
<th>ANSALDO Components (<strong>HRP technology</strong>)</th>
<th>PLANSEE Components (<strong>HIP technology</strong>)</th>
</tr>
</thead>
</table>

**CFC Components** (Front Side)
*(SATIR pre-testing examination)*

- DTrefmax (°C)
- `Faulty tile` threshold: 9°C
- `Detectability` threshold: 5°C

**Overall good bonding quality**
*Ref. F. Escourbiac (PFMC-2009)*

**Heat Transfer Capability**

- ‘LOW’
- ‘GOOD’ (acceptable)
Qualification of CFC armoured components

**SATIR Pre-Examination for ‘Not-repaired’ / ‘Repaired’ Components (2/3)**

- **ANSALDO Components (HRP technology)***
- **PLANSEE Components (HIP technology)***

**CFC Components (Front Side)**

(SATIR pre-testing examination)

<table>
<thead>
<tr>
<th>DTrefmax (°C)</th>
<th>N° Tile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Heat Transfer</td>
<td></td>
</tr>
<tr>
<td>« Dectectability » threshold*</td>
<td></td>
</tr>
<tr>
<td>« Faulty tile » threshold*</td>
<td></td>
</tr>
</tbody>
</table>

**Overall good bonding quality / 2 tiles (~3%) with low heat transfer capability**
Qualification of W armoured components

**SATIR Pre-Examination for ‘Not-repaired’ / ‘Repaired’ Components (1/2)**

- ANSALDO Components (HRP technology)
- PLANSEE Components (HIP technology)

**W Components** (Front Side)
(SATIR pre-testing examination)

- « Faulty tile » threshold*
- « Detectability » threshold*

- Heat Transfer Capability
  - ‘LOW’
  - ‘GOOD’ (acceptable)

- Overall good bonding quality

- ‘GOOD’ (acceptable)

- ‘LOW’

- « Faulty tile » threshold*

- « Detectability » threshold*

- Ref. F. Escourbiac (PFMC-2009), M. Richou (ICFRM-2009)
Qualification of W armoured components

**SATIR Pre-Examination** for ‘Not-repaired’ / ‘Repaired’ Components (2/2)

<table>
<thead>
<tr>
<th>N° Tile</th>
<th>Dtrefmax (° C)</th>
<th>Heat Transfer Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>2</td>
<td>6° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>3</td>
<td>7° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>4</td>
<td>8° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>5</td>
<td>9° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>6</td>
<td>10° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>7</td>
<td>11° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>8</td>
<td>12° C</td>
<td>‘GOOD’ (acceptable)</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>‘LOW’</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>‘LOW’</td>
</tr>
<tr>
<td>11</td>
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<td>‘LOW’</td>
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<tr>
<td>12</td>
<td></td>
<td>‘LOW’</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>‘LOW’</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>‘LOW’</td>
</tr>
</tbody>
</table>

**Overall good bonding quality**

ANSALDO Components (**HRP technology**)  
PLANSEE Components (**HIP technology**)

Parasite reflexion  
« Faulty tile » threshold*  
« Detectability » threshold*

Ref. F. Escourbiac (PFMC-2009), M. Richou (ICFRM-2009)
Summary

- **SATIR PRE-EXAMINATION of 19 components** (~70 CFC tiles & ~95 W tiles)
  - Including 12 (~7%) « repaired » tiles distributed out 11 components

- **Overall good bonding quality** in terms of « heat transfer capability » after manufacturing process for both CFC or W armoured components, whatever the bonding technology!

*Pre-examination in agreement with the Initial Thermal Mapping at 5MW/m²*
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Damage Valuation after Thermal Fatigue for CFC armoured components

Summary of events during the thermal fatigue

ITER requirement (Baffle Region)

ITER requirement (Strike-Point Region)

No visible damage

Alteration of surface

Slight erosion

High (extended) erosion

CFC-NB31* HRP

CFC-NB41* HRP / HIP

Front View (NO VISUAL DAMAGE)

Front View (SLIGHT EROSION)

Front View (EROSION)

*Ref. M. Richou (SOFT-2010)
Damage Valuation after Thermal Fatigue for CFC armoured components

**SATIR Post-Examination for ‘Not-repaired’ / ‘Repaired’ Components**

- **ANSALDO Components** *(HRP technology)*
- **PLANSEE Components** *(HIP technology)*

**Surface Erosion (by sublimation) correlated with a degradation of heat transfer capability**
Damage Valuation after Thermal Fatigue for W armoured components

**Summary of events during the thermal fatigue***

ITER requirement (Baffle Region)

- 0 MW/m²
- 500°C
- 1000°C

ITER requirement (Strike-Point Region)

- 15 MW/m²
- 1000°C

- 20 MW/m²
- 1000°C

<table>
<thead>
<tr>
<th>Damage Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No visible damage</td>
<td>Alteration of surface</td>
</tr>
<tr>
<td>Surface Melting</td>
<td>Longitudinal (mm) Cracks</td>
</tr>
<tr>
<td>High roughness</td>
<td>Network (µm) cracks</td>
</tr>
<tr>
<td>Located (droplets)</td>
<td>Extended (from surface)</td>
</tr>
</tbody>
</table>

*Ref. P. Gavila (SOFT-2010)

**Ref. M. Richou (SOFT-2010)
**Damage Valuation after Thermal Fatigue for W armoured components**

**SATIR Post-Examination** for ‘Not-repaired’ / ‘Repaired’ Components

- Melted tiles
- Partially melted tiles
- Start of debonding

- Repaired tiles
- HIP Technology
- HRP Technology

**Key Points**

- Surface melting correlated with a degradation of heat transfer capability
- Surface alteration does not impair the heat transfer capability
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- Damage Valuation after Thermal Fatigue Testing

- Summary & Conclusion
Summary & Conclusion

- Qualification of CFC/W components after Manufacturing Phase
  - Good bonding quality of CFC/W armoured components including recent/consolidated (European) development: Optimization/Reliability of bonding technologies, Repairing process

- Damage valuation after thermal cycling (up to $20\,\text{MW/m}^2$) in steady state

**ITER REQUIREMENT (normal operation)**

- **Phase 1:** “Mixed CFC / W”
  - Target (strike-point region) / CFC armour:
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  - Target (baffle region) / W armour:
    - 5 MW/m$^2$ steady state, 3000 pulses
    - 10 MW/m$^2$ during 2 seconds, 300 pulses

- **Phase 2:** “Full W”
  - W up to $20\,\text{MW/m}^2$ in steady state!

- Start of embrittlement in surface at $15\,\text{MW/m}^2$
- Spread of embrittlement in surface at $20\,\text{MW/m}^2$
  - significant altered surface (cracks, located surface melting)
  - repairing process validated (up to 500 cycles) for HIP techno. and a few cycles for HRP technology

Good (thermomechanical) behaviour

Slight (located) erosion phenomenon in surface after 500 cycles (with a low heat transfer degradation)

Good (thermomechanical) behaviour

Start of embrittlement in surface at $15\,\text{MW/m}^2$

- Spread of embrittlement in surface at $20\,\text{MW/m}^2$
  - significant altered surface (cracks, located surface melting)
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Summary & Conclusion

- **Qualification of CFC/W components after Manufacturing Phase**
  - **Good bonding quality** of CFC/W armoured components including recent-consolidated (European) development: Optimization/Reliability of bonding technologies, Repairing process

- **Damage valuation after thermal cycling (up to 20 MW/m²) in steady state**

Europe has with ITER margin requirements the suitable technologies (including the repairing process) with regard to CFC/W armoured components for ITER divertor heat loads foreseen during the initial ‘non-active’ phase (Phase 1).

R&D are still needed for a ‘full W’ divertor foreseen during the ‘active’ phase (Phase 2), where a prolonged use of W-armoured components above recrystallization (high temperature usage) and under DBTT should be considered for strike-point region of ITER Divertor.
THANK YOU FOR YOUR ATTENTION