Assessment of CFC grades under thermal fatigue for the ITER inner vertical target

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Introduction: The ITER divertor system aims to exhaust a significant part of the plasma power and to minimize the helium and impurity content in the plasma.. The Inner Vertical Target (IVT), to be delivered by European domestic agency, is constituted of Carbon Fibre Composite (CFC) monoblocks in the lower part and tungsten (W) monoblocks in the upper part. The CFC armour material must have some technical and non-technical requirements . CFC must have high mechanical and thermal properties fitting to the PFC manufacturing process (joining CFC to a CuCrZr tube) and to the inspection requirements (detecting defect at CFC to CuCrZr interface). Moreover, PFC and CFC must be adapted to the in service needs. The objective of the paper is to report on PFC made with different techniques and with different CFC grades (N31, NB31, N11, NB41, DMS814, DMS780, Dunlop 3D and SGL sigrabond) about their inspection after manufacturing and about their thermal behavior under thermal loads.

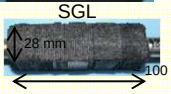
Experimental description

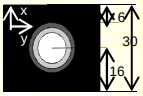
Samples/ CFC grades :

HIP component | HRP component | N11

Dunlop 3D ~ DMS814 | N31~NB31~NB41 | DMS780

SGL





1 mm CuOFHC

1.5 mm CuCrZr

Thermal conductivity $Wm^{-1}K^{-1}$	λxx		λyy		λzz		Structure	Fibers
	20°C	1000°C	20°C	1000°C	20°C	1000°C		
SNECMA NB41	427	186	111	55	80	42	3D	Ex-pitch(x),ex-PAN(y) and needled fibers(z, ex-PAN)
Dunlop 3D	320	140	110	50	60	25	3D	Ex-pitch(x),ex-PAN(y) and needled fibers(z, ex-PAN)
SNECMA N11	240	80	240	80	150	55	3D	Ex-PAN(x),ex-PAN(y) and needled fibers(z, ex-PAN)
SNECMA NB31	260	120	100	48	85	40	3D	Ex-pitch(x),ex-PAN(y) and needled fibers(z, ex-PAN)
SNECMA N31	300	150	115	60	90	45	3D	Ex-pitch(x),ex-PAN(y) and needled fibers(z, ex-PAN)
DMS814	282		126		62		2D1/2	Ex-pitch(x),ex-PAN(y) and needled fibers(z, ex-PAN)
DMS780	256*	100	256*	100	48.4	25	2D	Ex-PAN(x),ex-PAN(y)

* Extrapolated from T=300°C

- Two E.U. industries:
  Ansaldo Ricierche (ANSALDO), PLANSEE SE (PLANSEE)
- 31 components (155 CFC monoblocks)
- CFC grades :
  - SNECMA : N11 (3D, x=y), NB31, N31, NB41 (3D, x≠y)
  - DUNLOP : 3D, DMS814 (2D½, x≠y) DMS780 (2D, x=y)
  - SGL : Sigrabond (3D, x≠y)
- Cu/CuCrZr joining; ANSALDO: Hot Radial Pressing (HRP)®
  PLANSEE: Hot Isostatic Pressing (HIP)®
- CFC/Cu joining; ANSALDO: Pre brazed casting(PBC) ®
  PLANSEE: Active Metal Casting (AMC)®

High Heat Flux testing at FE200 facility :

(Electron beam gun 200 kW, AREVA)

Thermal Flux / MW m-2	10	20
NB31_HRP, NB41_HIP	No	1000 cycle(1)
NB41_HRP, 3D_HRP, DMS814_HRP	1000 cycle	1000 cycle(1)

(1) Followed by a flux increase up to 35 MWm^{-2}

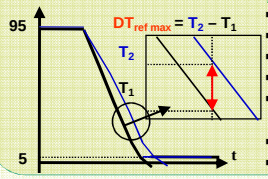
- 3 mock-ups (10 components, i.e. 50 monoblocks)
- Each area: cycles of 10 s with heating, followed by 10 s without heating
- Thermal mapping after each thermal flux load step 5MWm^{-2}
- Surface temperature measurement with IR camera

Evaluation of component quality after manufacturing with SATIR, CEA

DTref_max results

- Overall good quality of all components
- N11 and DMS780 (Good quality)
- N31, NB31, NB41, Dunlop 3D and DMS814
  (In average good quality)
- SGL (Low quality)
- Highest DTref_max for :
  - NB41_HRP and SGL_HIP components
- Out of specification for NB31_HRP#2 CFC grade

SATIR principle



- Station d'Acquisition et Traitement Infrarouge, CEA
- Assess the thermal exhaust capability
- Thermal shock: hot water (95°C) / cold water (5°C)
- Transient monitoring with IR thermography on front side
- Surface temperature comparison:
  inspected component / reference
- Before HHF tests
- After HHF tests

Time response results

For all components :
- Overall good quality
- ~ N11/DMS780 >
- ~ N31/NB31/NB41/ Dunlop 3D/DMS814>
- SGL

For HRP components:
- Dunlop 3D > NB41

DTref_max(pre HHF) with optimised reference

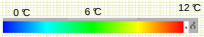
CFC Grades	HRP Number mono	HRP DTref_max / °C <5	HRP DTref_max / °C 5<<9	HRP DTref_max / °C 9<	HIP Number mono	HIP DTref_max /°C <5	HIP DTref_max /°C 5<<9	HIP DTref_max /°C 9<
N31	10	6	4	0	10	9	1	0
NB31	15	12	3	0	0	0	0	0
NB41	15	10	2	**3**	20	20	0	0
Dunlop 3D	10	7	3	0	20	20	0	0
DMS814	5	5	0	0	0	0	0	0
N11	15	15	0	0	20	20	0	0
DMS780	0	0	0	0	10	10	0	0
SGL	0	0	0	0	5	0	0	**5**

DTref_max and quality of components

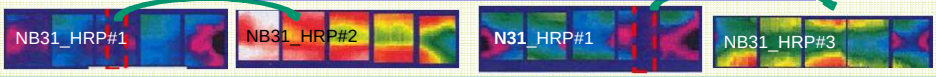
	Good	Medium (5 °C)	Low (9 °C)
N31/ NB31 NB41/Dunlop 3D DMS814	85 %	12 %	3 %
N11/DMS780	100 %	0	0
SGL	0	0	100 %

Time response / s

	HRP Cartography	HRP max	HRP av.	HIP Cartography	HIP max	HIP av.
N31		4.6	2.1		4.4	2.1
NB31		4.2	2.2	Not available		
NB41		5.8	2.3		3.6	2.1
Dunlop 3D		3.8	2.1		3.4	2
DMS814		4.7	2.1	Not available		
N11		2.6	1.9		2.3	1.9
DMS780	Not available				2.2	1.9
SGL	Not available				20	4



DTref_max with NB31_HRP#1 and N31_HRP#1 as references



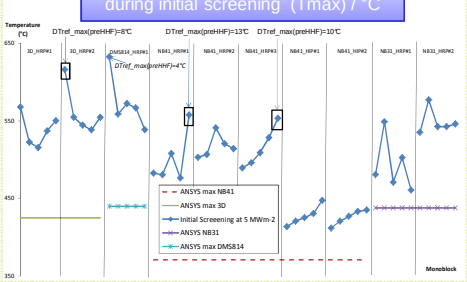
Better thermal exhaust capability for components with CFCs with fibers equivalent in x and y directions (ex: N11) than components with CFCs with fibers different in x and y directions (ex: NB41)
➡ Joining CuOFHC to CFC(x=y) is easier than to CFC(x≠y)

Evaluation of component quality under thermal fatigue tests (SATIR <=> thermal screenings)

Initial screening results:

- Overall good quality of all components
- Consistent with SATIR results
  - Tmax: 3D_HRP> NB41_HRP> NB41_HIP
  - 3 monoblocks emerge (DTref_max=8°C, 13°C, 10°C)
  - Tmax: NB31_HRP#2>NB31_HRP#1

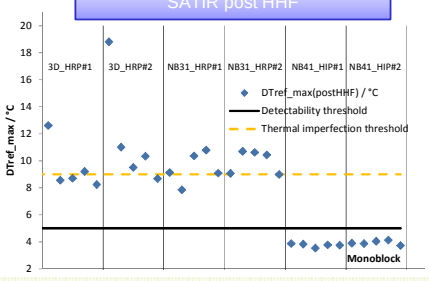
Maximum surface temperature during initial screening (Tmax) / °C



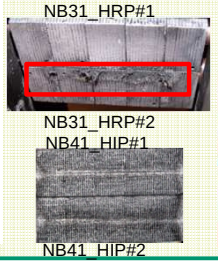
After thermal fatigue tests:

- Good quality of NB41_HIP
- 3D_HRP and NB31_HRP underwent thermal degradation in terms of heat transfer capability
- Erosion is visually less important for NB41_HIP than for other HHF tested components
- Erosion is due to sublimation which may be explained with an higher temperature during thermal loads (defect and/or thermal conductivity degradation)

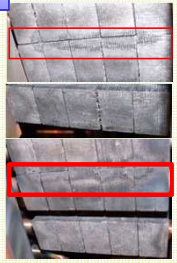
SATIR post HHF



Visual observation after cycles at 20 MWm^{-2}



Erosion zones



Conclusion

- **31 components with different CFC grades were studied after their manufacturing with SATIR infrared thermography**. The results are :
  - Overall good quality after manufacturing.
  - A better thermal exhaust capability for components with CFCs with fibers equivalent in x and y directions than for components with CFCs with fibers different in x and y directions
  - Presence of 3 important thermal imperfections which were noticed during initial thermal mapping
  - One component out of CFC grade specification, which was not clearly observed with initial screening and clearly observed with final screening
- **During HHF tests up to 1000 c at 20MWm^{-2}, no water leak occurred**. **Erosion** is visually noticed and depends on CFC grade,