WATER CHEMISTRY CONTROL AS CORROSION MITIGATION STRATEGY

Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission Reactors

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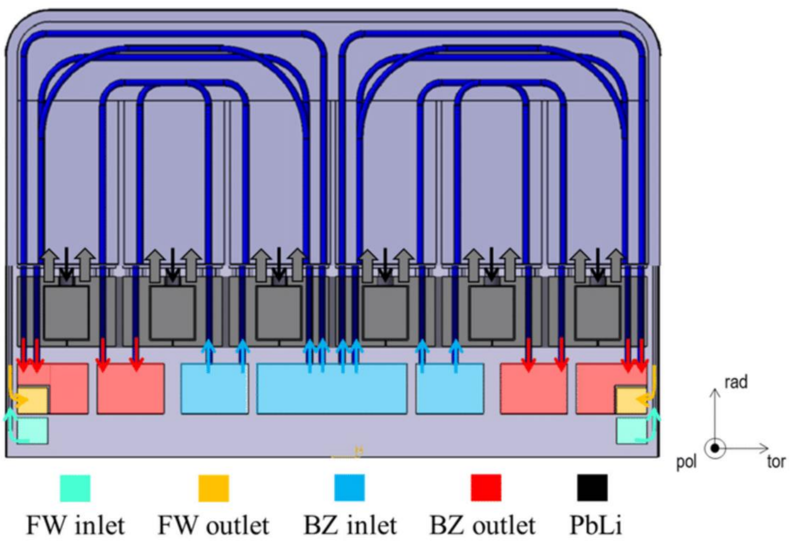
OUTILNE

- Framework and scope of the work
- Case study: water solution and safety
- Testing loop: how does it work
- Pre-Test phase
- Test phase and main parameters
- Post-Test phase
- Results
- Conclusions

FRAMEWORK AND GOALS

Framework: *Validation of water chemistry for the EU-DEMO WCLL Breeding Blanket with corrosion test of iron-based alloys*



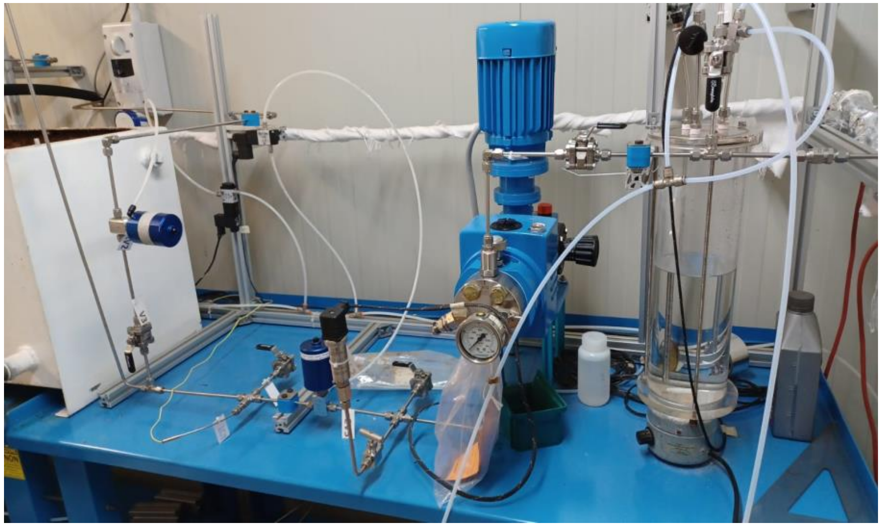
Goal: *Identification of the pH stability and oxygen concentration threshold to avoid localized corrosion phenomena*

CASE STUDY: WATER SOLUTION AND SAFETY

- The work has been carried out considering a solution of Ultra Pure Water and KOH
- The KOH has been chosen considering the successful pH control in VVER design
- Into water cooling pipeline the presence of water solution means the presence of corrosion products
- The corrosion products can be activated when exposed to a radiation field
- In case of structural damages the activated corrosion products can contaminate the environment

EXPERIMENTAL CAMPAIGN – HPHT LOOP

- The loop is located in laboratories of RINA-CSM
- Temperature range: 300 ° C - 25 ° C
- Fluid velocity: 2 m/s
- Pressure: 100 bar



EXPERIMENTAL CAMPAIGN – SPECIMENS

- Specimens are produced at RINA-CSM laboratory

- Hot rolled coupon with composition:

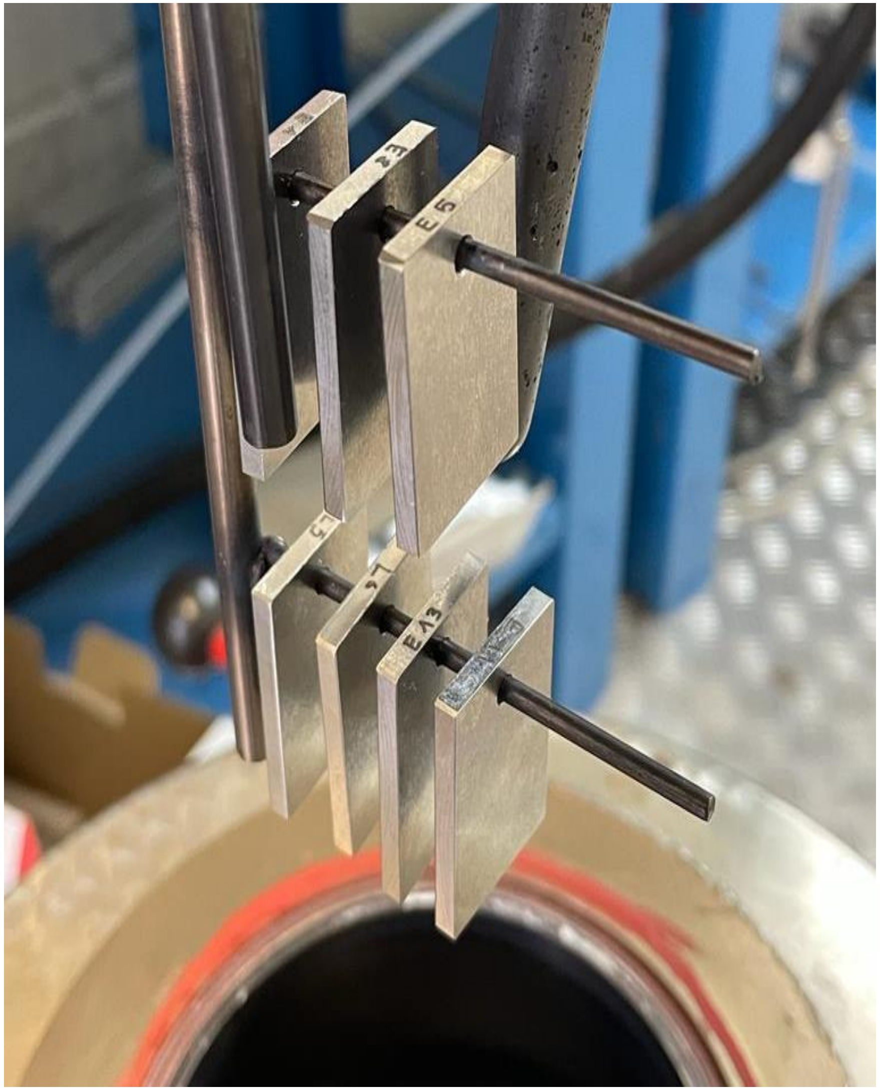
  the EUROFER coupon are hot rolled with dimension of 20x30x3 mm, the chemical compositions (wt%) is:

Material	Cr	Ni	Mn	Ti	V	Al	Ta	W	Mo
EUROFER-97	8.89	0.01	0.51	0.005	0.34	0.01	0.10	0.92	0.01
	C	**Si**	**P**	**Sn**	**Sb**	**N**	**S**	**Co**	**Nb**
	0.11	0.05	0.005	0.001	0.001	0.21	0.003	0.06	0.01

  the SS316L coupons are hot rolled with finishing type 2B, with dimensions of 20x30x4 mm, the chemical compositions (wt%) is:

Material	C	Mn	Cr	Ni	Ti	Mo	Si	Cu
AISI 316L	0.01	1.0	16.63	10.1	0.007	2.06	0.32	0.37

EXPERIMENTAL CAMPAIGN – PRE TEST PHASE



Specimens	All of the specimens are weighted before the test EUROFER degreasing
Solution	pH measurement
Test apparatus	Cleaned and deareated

- The specimens are located into the autoclave body after pre-test phase
- All the specimens have an alphanumeric identification code
- Both EUROFER and SS316L have been tested

EXPERIMENTAL CAMPAIGN – TESTS

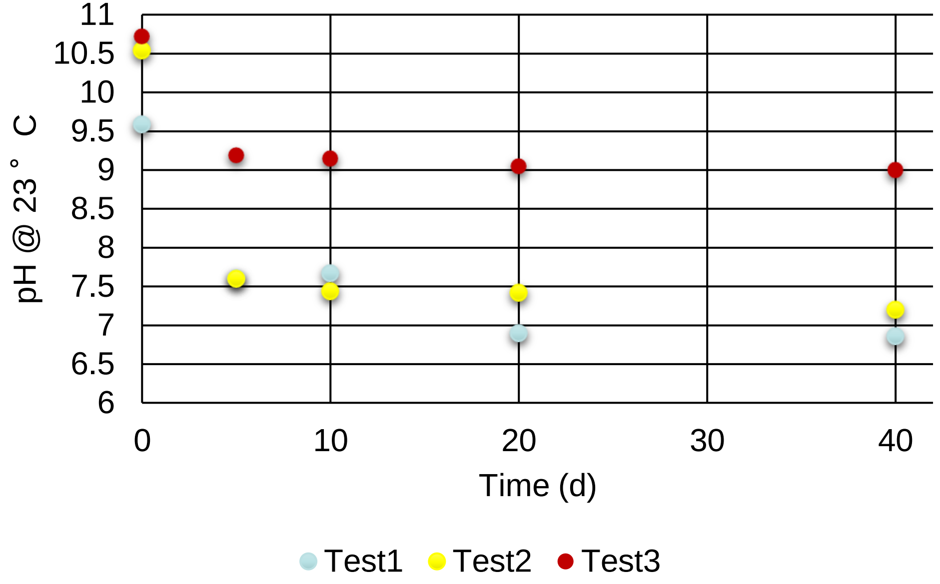
Test N.	Solution	O_2 [ppb]	Specimen type	Pressure [bar]	Temperature [° C]	Time [h]	Aim
1	KOH (5 ppm)	< 10	EUROFER SS316L	100	300	1000	Looking for pH stability
2	KOH (26 ppm)	< 10	EUROFER SS316L	100	300	1000	
3	KOH (52 ppm)	< 10	EUROFER SS316L	100	300	1000	
4	KOH (52 ppm)	100	EUROFER	100	300	1000	Looking for localized phenomena
5	KOH (52 ppm)	200	EUROFER SS316L	100	300	1000	
6	KOH (52 ppm)	300	EUROFER SS316L	100	300	1000	

- A pH time dependent trend has been obtained by tapping the solution once a week
- The same amount of the tapped solution is reintroduced from the deaeration vessel
- After each test the specimens are individually packed and the solution is taken for the post test analysis

EXPERIMENTAL CAMPAIGN – POST TEST PHASE

The procedure is divided in several steps:

- ❑ Specimens: weighted, analysed with optical microscope and SEM
- ❑ Solution: analysed for pH and releases. From the Test 1, Test 2 and Test 3 there is a pH trend in figure
- ❑ Test apparatus: drained and cleaned



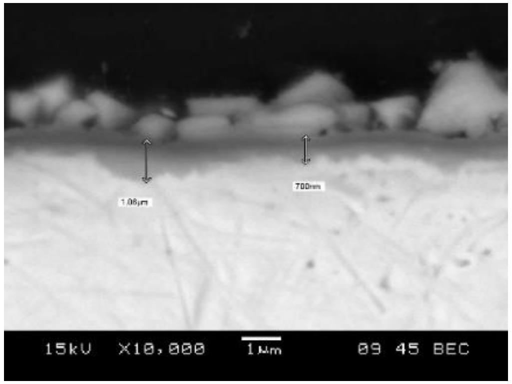
EXPERIMENTAL CAMPAIGN – RESULTS

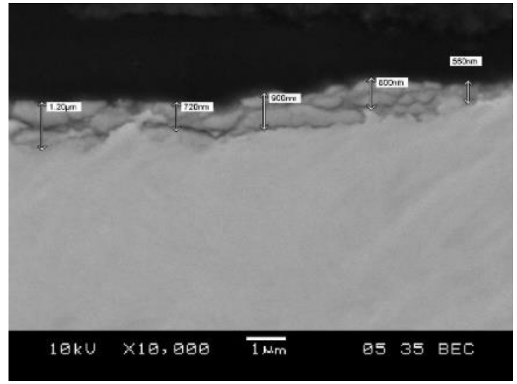
Test N.	Material	Corrosion Rate w/o pickling treatment [μm/y]	Corrosion rate with pickling treatment (HCl + HMTA) [μm/y]
1 KOH 5 ppm O_2 <10 ppb	EUROFER	3.0 ÷ 3.2	7.6
	SS316L	0.1 ÷ 0.2	1
2 KOH 26 ppm O_2 <10 ppb	EUROFER	1.9 ÷ 2.6	5.1
	SS316L	0.3 ÷ 0.4	1
3 KOH 52 ppm O_2<10 ppb	EUROFER	2.59 ÷ 2.73	5.9 ÷ 6.7
4 KOH 5 ppm O_2 100 ppb	EUROFER	0.15 ÷ 1.8	1.2 ÷ 4.16
	SS316L	0.22 ÷ 0.52	0.6
5 KOH 5 ppm O_2 200 ppb	EUROFER	3.48 ÷ 4.4	6.5 ÷ 8.04
	SS316L	0.15 ÷ 0.45	0.59÷ 0.6
6 KOH 5 ppm O_2 300 ppb	EUROFER	0.38÷ 2.7	0.38 ÷ 4.1
	SS316L	0.15 ÷ 0.69	0.15 ÷ 0.69

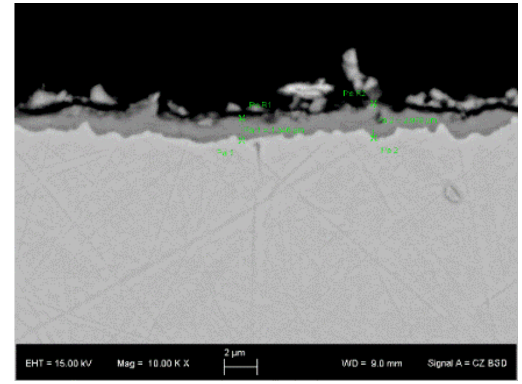
- ❑ The ASTM G1 procedure has been respected
- ❑ The corrosion rate has been evaluated using the weight loss of the specimens

EXPERIMENTAL CAMPAIGN – RESULTS

Section view

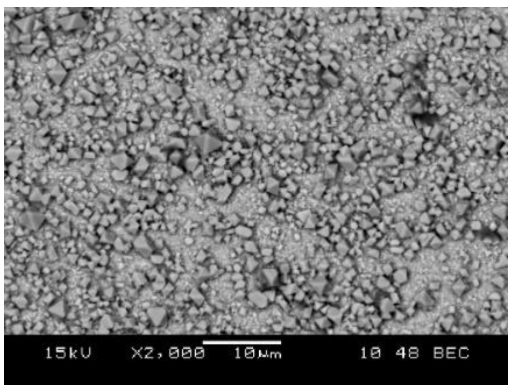


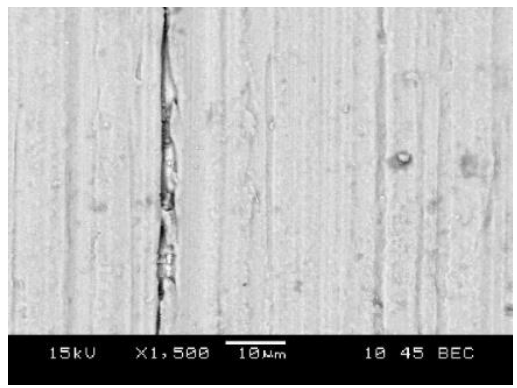


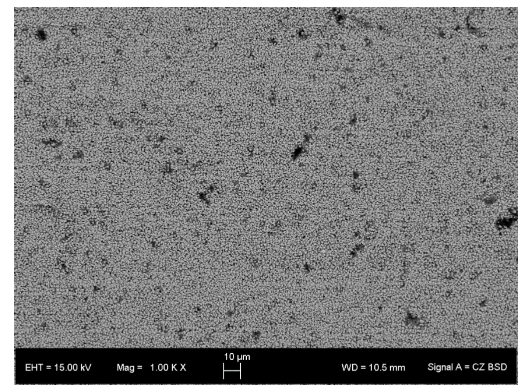


Test 4 (KOH 52 ppm, O_2 100 ppb) | Test 5 (KOH 52 ppm, O_2 200 ppb) | Test 6 (KOH 52 ppm, O_2 200 ppb)

Surface view







Ox. Layer thickness [μm]	0.7 - 1.06	0.56 - 1.2	1.346 - 2.078
Composition (wt%)	Fe72% Cr14% O12.6% Fe79% Cr2% O17%	Fe68.6% Cr19.8% O13.8% Fe85% Cr3.8% O9.76%	Fe66.8% Cr18.11% O14.06% Fe79.6% Cr2.04% O16.23%

CONCLUSIONS (1/2)

- The water solution validation is a support for the BB design about material performance and safety issues.
- The water chemistry has been optimized with the first three tests, to reach a stable pH trend during the test with KOH concentration of **52 ppm**.
- The higher oxygen concentration the higher corrosion layer thickness
- The oxide layer has been developed, protecting the base metal from localized corrosion phenomena
- In an environment w/o radiation field, and so radyolisis and structural damage, an oxygent concentration < **300 ppb** cannot start localized corrosion phenomena

CONCLUSIONS (2/2)

- An higher oxygen concentration can be induced by a lack of sealing for piping and joint areas
- Due to radiolysis the environment would be higher in oxydizing power, because of production of free radicals, oxygen and hydrogen peroxide. This means that in practical scenarios, lower oxygen concentration would be enough to create pits
- Double safety concern: a pit can cause **structural damages** being inducing phenomena as LOCA which can be a DBA. During a LOCA there is also **releases** of corrosion products activated by the radiation field, that are the most environmental concerning during accidental scenarios.

Thank you for the attention!

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RESULTS OF CHEMICAL ANALYSIS

Test N.	Fe [ppb]	Cr [ppb]	Ni [ppb]	Co [ppb]	Mo [ppb]	Cu [ppb]	W [ppb]	pH_{in} T=23° C	pH_{fin} T=23° C
1	36	0.3	5	<0.01	38	6	<0.01	9.59	6.86
2	42	3	41	<0.01	315	<0.5	5	10.54	7.20
3	113	15.5	21.2	0.36	246	5.3	18.0	10.72	9
4	68	3.6	14.4	<0.1	296	1.91	7.71	10.82	9.32
5	50.0	1.43	1.63	0.05	144.4	6.72	11.64	10.91	9.33
6	20.0	2.68	6.26	0.05	180.2	5.12	14.85	10.62	9.48

ACRONYMS

- Breeding Blanket (BB)
- Back Scattering Electron (BSE or BEC)
- Design Basis Accident (DBA)
- Energy Dispersive X-ray Spectroscopy (EDS or EDX)
- HexaMethyleneTetrAmine (HMTA)
- Secondary Electron (SE or SEC)
- Scanning Electron Microscopy (SEM)

Key insights related to tests (1-6)

- By varying the KOH concentration in Tests 1 to 3, our aim is to identify the threshold concentration that maintains pH stability throughout the test duration.
- The increase in oxygen concentration in Tests 4 to 6 could potentially induce localized corrosion, which is the primary observation target.
- The uniformity of the temperature, pressure, and test duration across all tests ensures that the effects of the variable parameters (KOH and O2 concentrations) can be studied in isolation.