Appendix 1

Welcome and introduction

Knovel Corrosion Content Strategy and DECHEMA Corrosion Handbook

S. Gurke

Appendix 2

List of participants

NAME	SURNAME	COMPANY	COUNTRY
Baak	Michael	Borealis Polyolefine GmbH	AUSTRIA
Bour Beucler	Valerie	Nalco Champion	FRANCE
Brandl	Ramona	OMV	GERMANY
Ciccomascolo	Francesco	Böhler Welding Holding GmbH	GERMANY
Claesen	Chris J	Nalco Champion	BELGIUM
De Landtsheer	Gino	Borealis	BELGIUM
Dubois	Francois	AXENS - IFP Technology Group	FRANCE
Escorza	Erick	Tenaris Dalmine	ITALY
Fullin	Luna	Tenaris Dalmine	ITALY
Gabetta	Giovanna	Eni	ITALY
Gierlinger	Matthias	Borealis Polyolefine GmbH	AUSTRIA
Hofmeister	Martin	Bayernoil Raffineriegesellschaft mbH	GERMANY
Holmes	Tracey	Special Metals	UK
Kuhn	Michael	PPG	UK
Mannucci	Michele	Termisol Termica S.r.l.	ITALY
Marcolin	Giacomo	Tenaris Dalmine	ITALY
Poldi	Matteo	Eni	ITALY
Preuss	Karsten	Shell Deutschland Oil GmbH	GERMANY
Rehberg	Thomas	KAEFER Isoliertechnik GmbH & Co. KG	GERMANY
Renaud	Lionel	Total raffinage Chimie	FRANCE
Ropital	François	IFP Energies nouvelles	FRANCE
Schempp	Philipp	Shell Deutschland Oil GmbH	GERMANY
Suleiman	Mabruk	Takreer	UNITED ARAB EMIRATES
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS

Appendix 3

EFC WP15 Activities

(F. Ropital)

Presentation of the activities of WP15

European Federation of Corrosion (EFC)

- Federation of 29 National Associations
- 21 Working Parties (WP) and 1 Task Force
- Annual Corrosion congress « Eurocorr »
- Thematic workshops and symposiums
- Working Party meetings (for WP15 twice a year)
- Publications

for more information http://www.efcweb.org

EFC Working Parties

http://www.efcweb.org

- WP 1: Corrosion Inhibition
- WP 3: High Temperature
- WP 4: Nuclear Corrosion
- WP 5: Environmental Sensitive Fracture
- WP 6: Surface Science and Mechanisms of corrosion and protection
- WP 7: Education
- WP 8: Testing
- WP 9: Marine Corrosion
- WP 10: Microbial Corrosion
- WP 11: Corrosion of reinforcement in concrete
- WP 12: Computer based information systems
- WP 13: Corrosion in oil and gas production
- WP 14: Coatings
- WP 15: Corrosion in the refinery industry
  (created in sept. 96 with John Harston as first chairman)
- WP 16: Cathodic protection
- WP 17: Automotive
- WP 18: Tribocorrosion
- WP 19: Corrosion of polymer materials
- WP 20: Corrosion by drinking waters
- WP 21: Corrosion of archaeological and historical artefacts
- WP 22: Corrosion control in aerospace
- Task Force on Corrosion in CO_2 Capture Storage (CCS) applications
- Task Force on Corrosion reliability of Electronics

EFC Working Party 15 « Corrosion in Refinery » Activities

http://www.efcweb.org/Working+Parties-p-104085/WP%2B15-p-104111.html

Chairman: Francois Ropital   Deputy Chairman: Johan Van Roij

Information Exchange – Forum for Technology
Sharing of refinery materials /corrosion experiences by operating company representatives (ie corrosion atlas).
Sharing materials/ corrosion/ protection/ monitoring information by providers

Eurocorr Conferences : organization of refinery session and joint session with other WPs (2018 Krakow-Poland, 2019 Seville-Spain)

WP Meetings
One WP 15 working party meeting in Spring,
One meeting at Eurocorr in September in conjunction with the conference,

Publications - Guidelines

Education – qualification – certification
List of "corrosion refinery" related courses on EFC website ?
Proposal of courses within Eurocorr ?

EFC Working Party 15 « Corrosion in Refinery »

List of the WP15 spring meetings :

10 April 2003	Pernis - NL (Shell)
8-9 March 2004	Milan -Italy (ENI)
17-18 March 2005	Trondheim- Norway (Statoil)
31 March 2006	Porto Maghera - Italy (ENI)
26 April 2007	Paris - France (Total)
15 April 2008	Leiden -NL (Nalco)
23 April 2009	Vienna - Austria (Borealis)
22 June 2010	Budapest - Hungary (MOL)
14 April 2011	Paris - France (EFC Head offices)
26 April 2012	Amsterdam - NL (Shell)
9 April 2013	Paris - France (Total)
8 April 2014	Mechelen - Belgium (Borealis)
14 April 2015	Leiden -NL (Nalco)
26 April 2016	Paris - France (Total)
13 April 2017	Frankfurt - Germany (EFC Head offices)

Publications from WP15

- EFC Guideline n°40 « Prevention of corrosion by cooling waters » available from http://www.oxbowbooks.com/oxbow/working-party-report-on-control-of-corrosion-in-cooling-waters.html

- EFC Guideline n° 55 Corrosion Under Insulation *New edition nov. 2015* http://store.elsevier.com/product.jsp?isbn=9780081007143&pagename=search

- EFC Guideline n° 46 on corrosion in amine units *A revision is in progress by a task force*

- Future publications – task forces : suggestions ?
  - best practice guideline to avoid and characterize stress relaxation cracking ?
  - impact of upstream inhibitors in refinery corrosion ?
  - other suggestions ?

WP15 Corrosion Atlas Web page

http://www.efcweb.org/Working+Parties/WP+Corrosion+in+the+Refinery+Industry/WP+15+Refinery+Corrosion+Atlas.html

Eurocorr 2017 & 20th ICC Congress

Prague Czech Republic 3-7 September 2017

Eurocorr 2017 (3-7 September) will be coupled with the 20th International Corrosion Council (ICC) congress (that takes place every 3 years in different parts of the world

Authors will be informed by the end of April

Refinery corrosion session on Tuesday 5th September afternoon and Wednesday 6th morning

Annual WP15 working party meeting during Eurocorr on Wednesday 6th September – to be confirmed -

http://eurocorr.org/EUROCORR+2017_+20th+ICC+_amp_+Process+Safety+Congress+2017-p-71180.html

Information :
Future conferences related to refinery corrosion

•3-7 September 2017
EUROCORR 2017 Prague Czech Republic

•28-30 November 2017
Stainless Steel World Conf 2017 Maastricht NL

•15-19 April 2018
CORROSION 2018 NACE Conf Phoenix AZ

9-13 September 2018
EUROCORR 2018 Krakow Poland

8-13 September 2019
EUROCORR 2019 Seville Spain

Look at the Website: www.efcweb.org/Events

Appendix 4

Austenitic stainless steel bismuth-free flux-cored wires for high-temperature applications

(F. Ciccomascolo)

Stainless Steel Bismuth Free Flux-cored Wires for High Temperature Applications

Elin M. Westin
Ronald Schnitzer
Francesco Ciccomascolo
Andrea Maderthoner
Kaj Grönlund
Gunilla Runnsjö

Voestalpine Böhler Welding Overview
We are part of voestalpine AG

Tool steel & leading position for high-speed steel & special forged parts

Special Steel Division

Turnouts, rails, processed wire, seamless tubes & welding consumables

Metal Engineering Division

Welding: 545 Mio EUR | 2,397 Employees

Steel Division

Premium steel strip, electrical steel strip, heavy plate, cast products

Metal Forming Division

High-quality metal processing solutions, precision steel strip & special components

11,2 Billion EUR | 47,418 Employees

ONE STEP AHEAD.

More than 145 years of know-how

in the steel industry
since 1870

in the welding consumables business
since 1926

mergers & acquisitions
of best-in-class welding companies:
Thyssen, Böhler, UTP, Avesta Welding,
Soudokay, Fontargen, Fileur, Maruti

a voestalpine company
since 2007

voestalpine
ONE STEP AHEAD.

Work with us around the globe

- 12 production sites
- customers in over 150 countries
- 43 locations in over 25 countries
- over 1,000 selected distribution partners

USTRIA | BELGIUM | BULGARIA
BRAZIL | CANADA | CHINA |
NY | FINNLAND | FRANCE
E | INDONESIA | INDIA |
LY | KOREA | MEXICO
RLANDS | NORWAY |
A | RUSSIA | SERBIA
E | SPAIN | SWEDEN |
ZERLAND | TURKEY
D ARAB EMIRATES |
KINGDOM | UNITED
STATES OF AMERICA

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Comprehensive portfolio

Products

- Covered electrodes
- Solid wires/TIG rods
- Flux cored wires
- Sub arc wire and flux
- Strips for strip cladding
- Solders, pastes, fluxes
- Post-weld cleaning chemicals and pickling pastes
- Thermal spraying powders

Alloys / Grades

- Unalloyed and low alloyed
- Aluminium
- Nickel-based alloys
- Special alloys (nickel, copper, cobalt)
- Stainless steel
- High strength
- High / low temperature
- Corrosion resistant
- Heat resistant

3 Business Units - 3 Brands

Effect of bismuth when welding with FCAW

Flux system of stainless steel FCAW usually contains bismuth
Small amount of bismuth (as Bi_2O_3) **improved slag detachability**
Bismuth content about 180-200 ppm
Bismuth has **no detrimental effect** when operating at working temperatures **lower than 400°C.**
Following aspects have been detected when welds are exposed at high temperature:

- intergranular **cracks** at temperatures ≥700°C
- **reduced hot ductility** >650°C
- **Decreased creep ductility** and premature creep failure
- fracture surface shows presence of bismuth/bismuth oxides

Crack sensitivity and loss of ductility due to segregation of bismuth or bismuth oxyde at grain boundaries

Consequences in the Petrochemical Industry Requirements

API RP 582 "Welding Guidelines for the Chemical, Oil, and Gas Industries"

Since 2nd Edition, Dec. 2009

> ***6.4.2.3*** *When austenitic stainless steel type FCAW weld materials are exposed to temperatures above 1000 °F (538 °C) during fabrication and/or during service:*
>
> *a) materials shall have a formulation that does not intentionally add bismuth, and bismuth in the deposited weld metal shall not exceed 0.002 % (20 ppm);*
>
> *b) materials shall have a maximum FN of 9 FN.*

Majors and Engineering Companies in Petrochemical started to adopt this recommendation in their specifications.

AWS A5.22:2012 or ASME BPVC sect. II part C SFA 5.22 (since Edition 2013)

A8.1.4 Bismuth(Bi) in Flux Cored Stainless Steel Electrodes

…..stainless steel electrodes containing Bismuth additions should not be used for such high temperature services or post weld heat treatment above about 900 °F (500 °C). Instead stainless steel flux cored electrodes providing no more than 20 ppm (0.002%) Bi in the weld metal should be specified …

Impact of FCWs Bi-free requirement in Petrochemical Industry

- Petrochemical C.P.E. **working temperature usually below 1000°F (538°C)** with exception of FCC Regenerators (@ 716°C -protective layer made in alloy 308H)
- **BUT when creep resistant steels are used, PWHT is carried out at temperatures above 1000°F (538°C)**
- Main C.P.E. equipment HC Reactors, HDS Reactors, Effluent Heat Exchangers are made in gr. 11. gr .22, gr. 22V needing PWHT

Therefore

- When stainless steel FCAW wires are used **for cladding C.P.E.** they must be **Bi-free type to meet the requirement of API RP 582**

<u>Challenge:</u> **development** of stainless steels FCAW wires **with a slag system without Bi addition** preserving **same weldability and slag detachability** of the usual wires

Heat Treatment- Actual / Simulation

DHT: Dehydrogenation heat treatment of 350° C for 4 hours is essential to minimize the susceptibility to cold cracking due to residual hydrogen in the weld.
ISR: Intermediate stress relieving is necessary, especially for highly restrained joints such as nozzle welds. The recommended temperature for ISR is 650 – 670° C for 4 hours [620°C for gr22] to ensure a partial elimination of the residual stresses in the weld.
PWHT: Post weld heat treatment for CrMo-22V has a very narrow tolerance in comparison to conventional steel grades. The recommended PWHT is 705° C for 8 hours.
Max PWHT: Several heat treatments are applied during fabrication, including DHT, ISR, and final PWHT. Sometimes, repairs are undertaken during fabrication. An additional cycle should be planned for any necessary repairs after installation. A maximum PWHT condition, which has an equal effect of all previously cited PWHT cycles, must be simulated. To that end, and to define one PWHT condition that covers all cycles, the Hollomon parameter (HP) of all the PWHTs should be calculated and then for any given time a PWHT temperature can be calculated vice versa.

- **PWHT Temperatures:**
  - 680°C (gr. 11), 690°C (gr. 22), 705°C (gr. 22V)
- **PWHT times applied in WQT:**
  - 8 h -10 h according the applied nominal PWHT in fabrication (3 – 4 h for gr. 11)
  - 24-32 h for simulating the equipment fabrication/repairing history.

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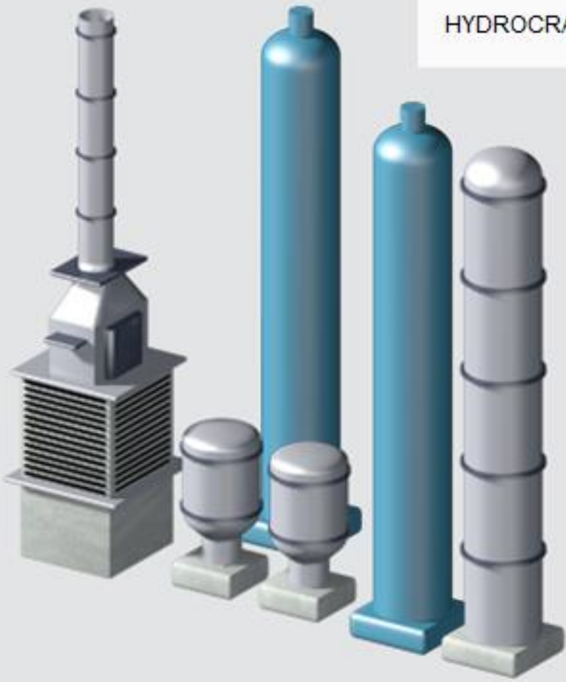
Hydrocracking Unit

böhler welding by voestalpine

BACK

HYDROCRACKING REACTOR



Related References

Related Documents

Base Material Grades

2 ¼ Cr 1 Mo Steel Grades

2 ¼ Cr 1 Mo ¼ V Steel Grades

Weld Overlay Grades

S.S 347

Show all products

Typical Service Temperature
425-482 Deg. C

Typical Service Pressure
200-210 bar

Typical Length
23,000-48,000mm

Typical Diameter
3,300-5,400mm

Typical Wall Thickness
223-358 +3mm

voestalpine
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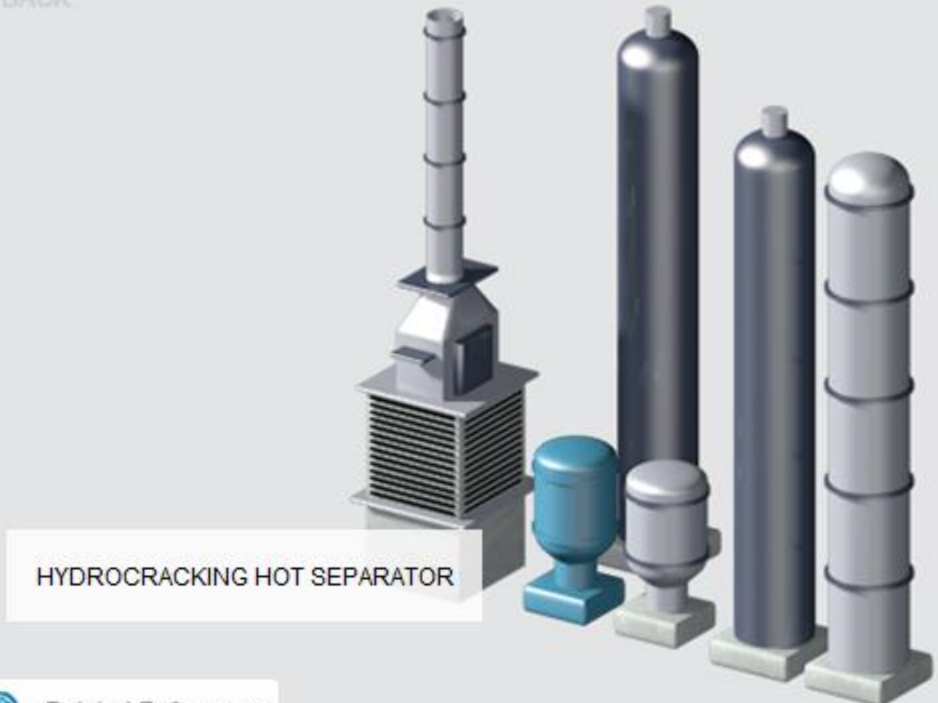
Hydrocracking Unit

böhler welding
by voestalpine

BACK



Related References

Related Documents

Find products

Base Material Grades

2 ¼ Cr 1 Mo Steel Grades

Weld Overlay Grades

S.S 347

Show all products

Typical Service Temperature
276

Typical Length
8,000-10,000mm

Typical Diameter
2,000-5,000mm

Typical Wall Thickness
80-90 +3mm

Typical Weight
40-90 MT

voestalpine
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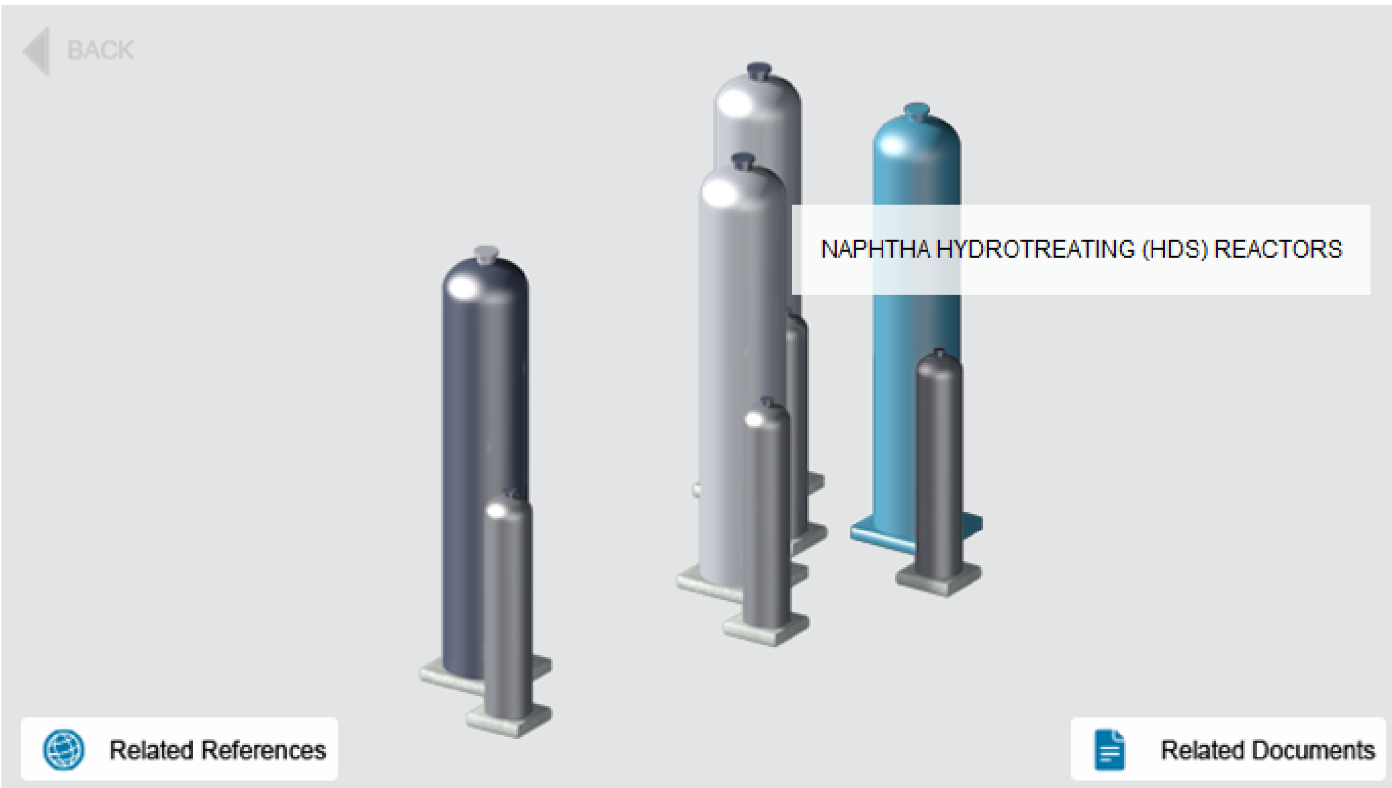
Hydrotreating Unit



Base Material Grades
- 2 ¼ Cr 1 Mo Steel Grades
- 2 ¼ Cr 1 Mo ¼ V Steel Grades

Weld Overlay Grades
- S.S 347

Show all products

Typical Service Temperature
425-482 Deg.C

Typical Service Pressure
173-210 bar

Typical Length
37,000-42,000mm

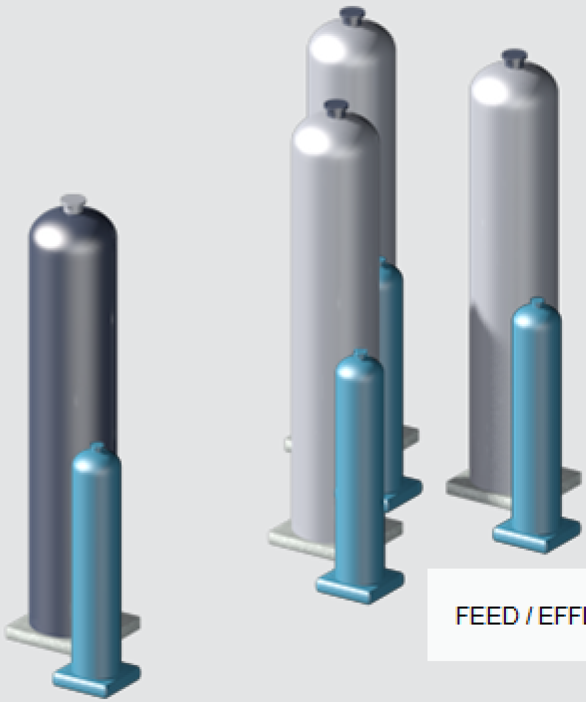
Typical Diameter
2,000-5,400mm

Typical Wall Thickness
120-200mm

Hydrotreating Unit

böhler welding by voestalpine

BACK



FEED / EFFLUENT HEAT EXCHANGER

Related References

Related Documents

Base Material Grades

- 1 ¼ Cr ½ Mo Steel Grades
- 2 ¼ Cr 1 Mo Steel Grades
- Cr-Mo5 and Cr-Mo9 Steel Grades

Weld Overlay Grades

- Alloy 625
- S.S 308L
- S.S 316L
- S.S 347

Show all products

Typical Service Temperature
360-550 Deg.C

Typical Length
10,000-20,000mm

Typical Diameter
1,000-4,000mm

Typical Wall Thickness
12-140mm

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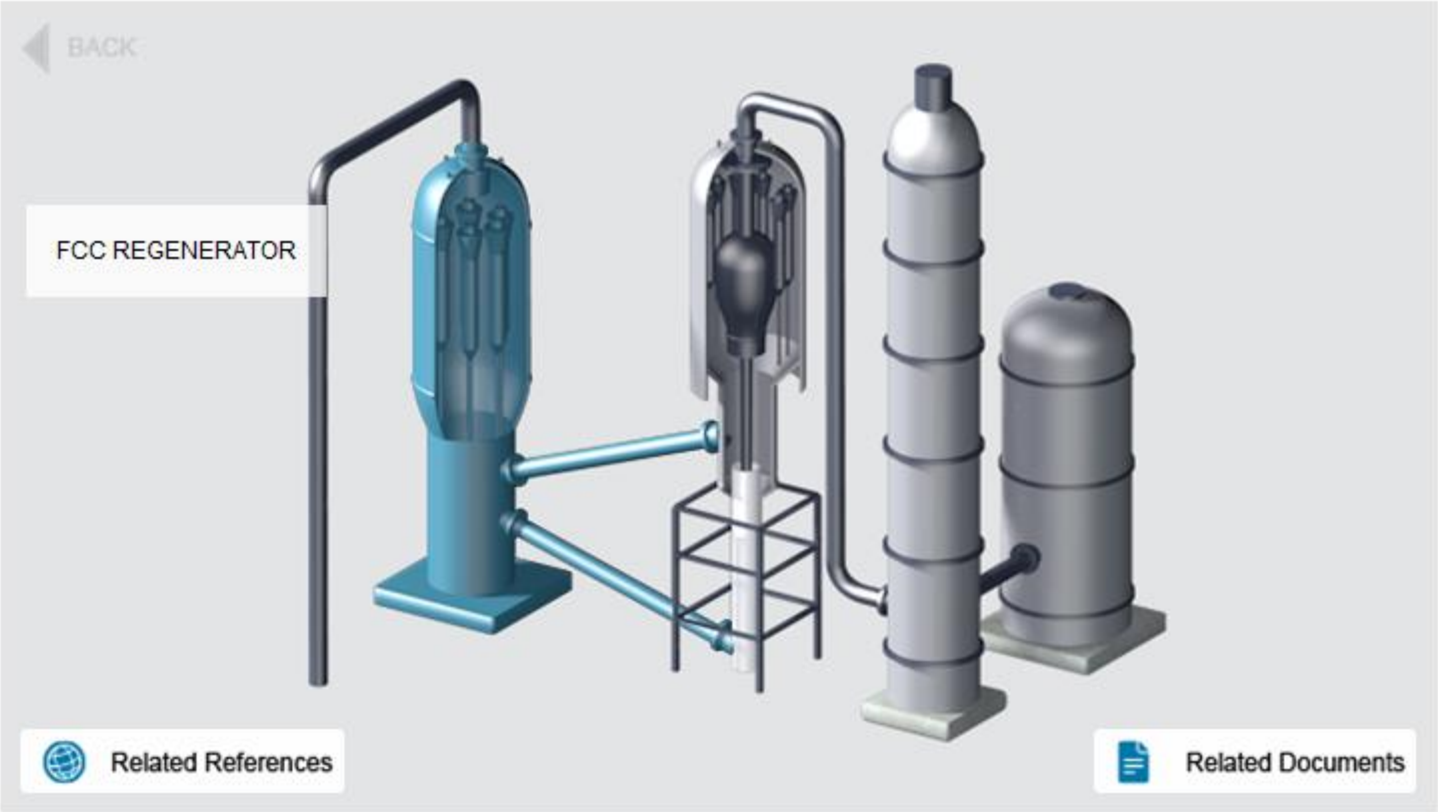
Fluid Catalytic Cracking Unit (FCCU)



Find products

Base Material Grades

C-Mn Steel Grades

Weld Overlay Grades

S.S 308H

Show all products

Typical Service Temperature
716 Deg.C

Typical Service Pressure
1.5-3 bar

Typical Length
20,000-39,000mm

Typical Diameter
10,000-15,000mm

Typical Wall Thickness
18-45 +3mm

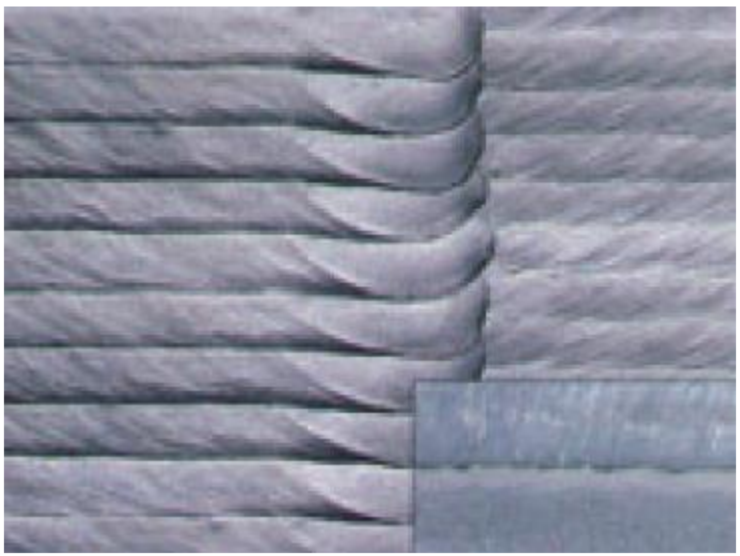
How to create a protective layer

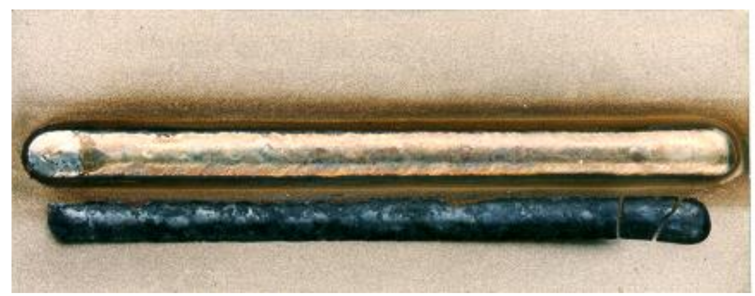
- ESW Weld Overlay
- Clad Plates
- **FCAW/SMAW/GTAW/SAW for completion, i.e.:**
  - **Inside nozzles, fittings and restoration**
  - **Weld overlay build-up of the internal "supports"**

Example on a dish-end

Advantages in cladding with SS FCAW

- High deposition rates and productivity
- Easy handling
- Smooth bead appearance
- Risk of porosity and lack of fusion minimized
- Low and easy post weld work
- Low shielding gas costs





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S.S. FCWs for High Temperature Service Joining Application

Welding of

- AISI 347, 347H, 321, 321H pipes

- AISI 304H pipes

Range of Böhler Bi-free wires for FCAW

Designation	EN	AWS
Böhler E 347L H-FD	T 19 9 Nb R M (C) 3	E347T0-4 (1)
Böhler E 347 H PW-FD	**T 19 9 Nb P M (C) 1**	**E347T1-4 (1)**
Böhler E 309L H-FD	T 23 12 L P M (C) 1	E 309LT0-4 (1)
Böhler E 309L H PW-FD	**T 23 12 L P M (C) 1**	**E309LT1-4 (1)**
Böhler E 308 H-FD	TZ 19 9 H R M (C) 3	E 308HT0-4 (1)
Böhler E 308 H PW-FD	**T Z 19 9 H P M (C) 1**	**E308HT1-4 (1)**

T0 type optimized for flat/horizontal welding: recommended for cladding
T1 type featuring fast-freezing slag system supporting welding pool when welding in out of position. Solution for joining (e.g. piping)

Chemical composition of SAS 2 PW-FD, SAS 2 PW-FD (LF) and E 347 H PW-FD

Typical values of all weld metal

Shielding gas: Ar + 18% CO_2

SAS 2 PW-FD (Standard)

C	Si	Mn	Cr	Ni	Nb	Ferrite*
0.030	0.8	1.3	19.0	10.5	0.45	10

SAS 2 PW-FD (LF)

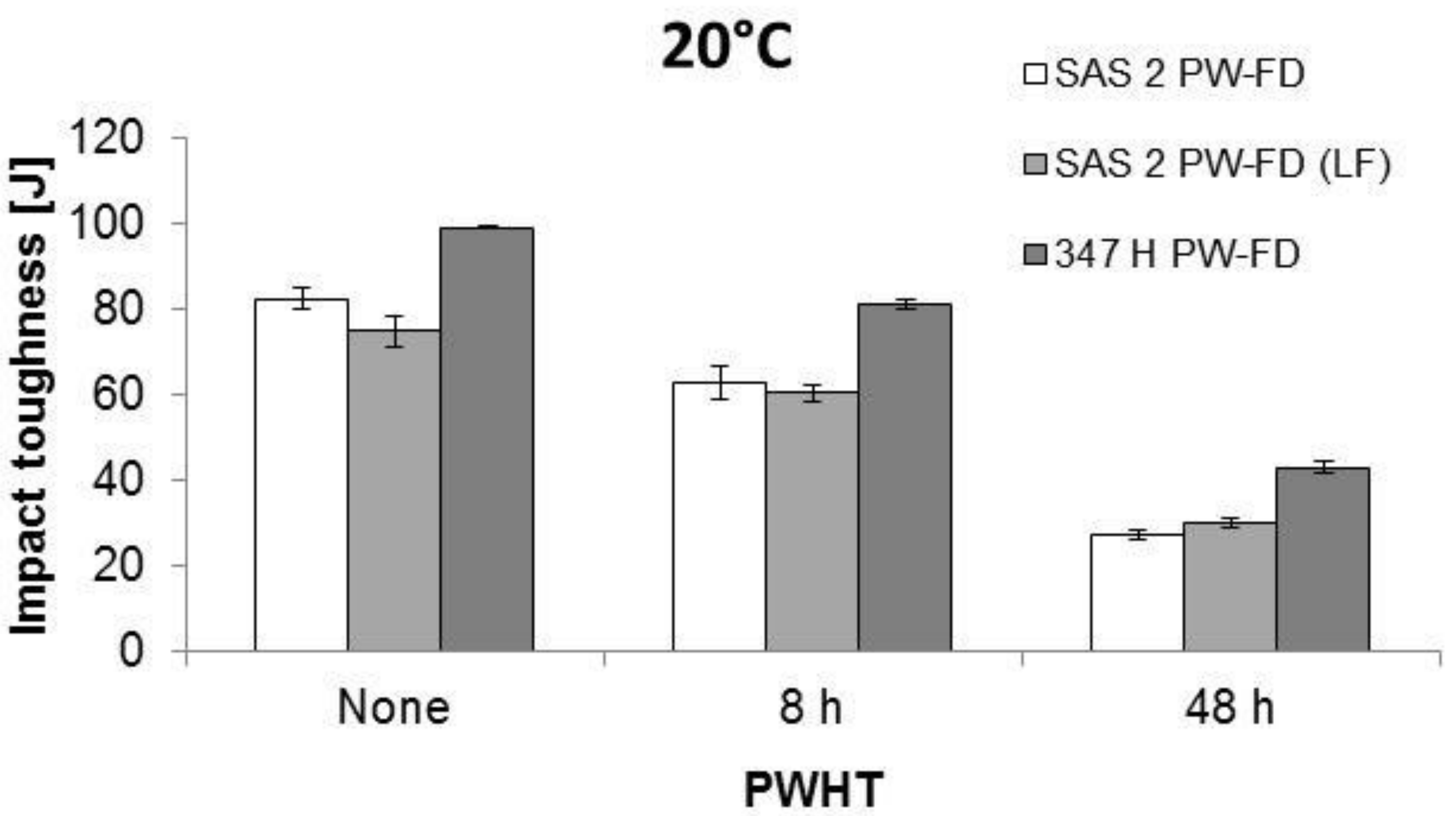
C	Si	Mn	Cr	Ni	Nb	Ferrite *
0.030	0.6	1.4	18.5	10.5	0.45	6

E 347 H PW-FD (without Bi)

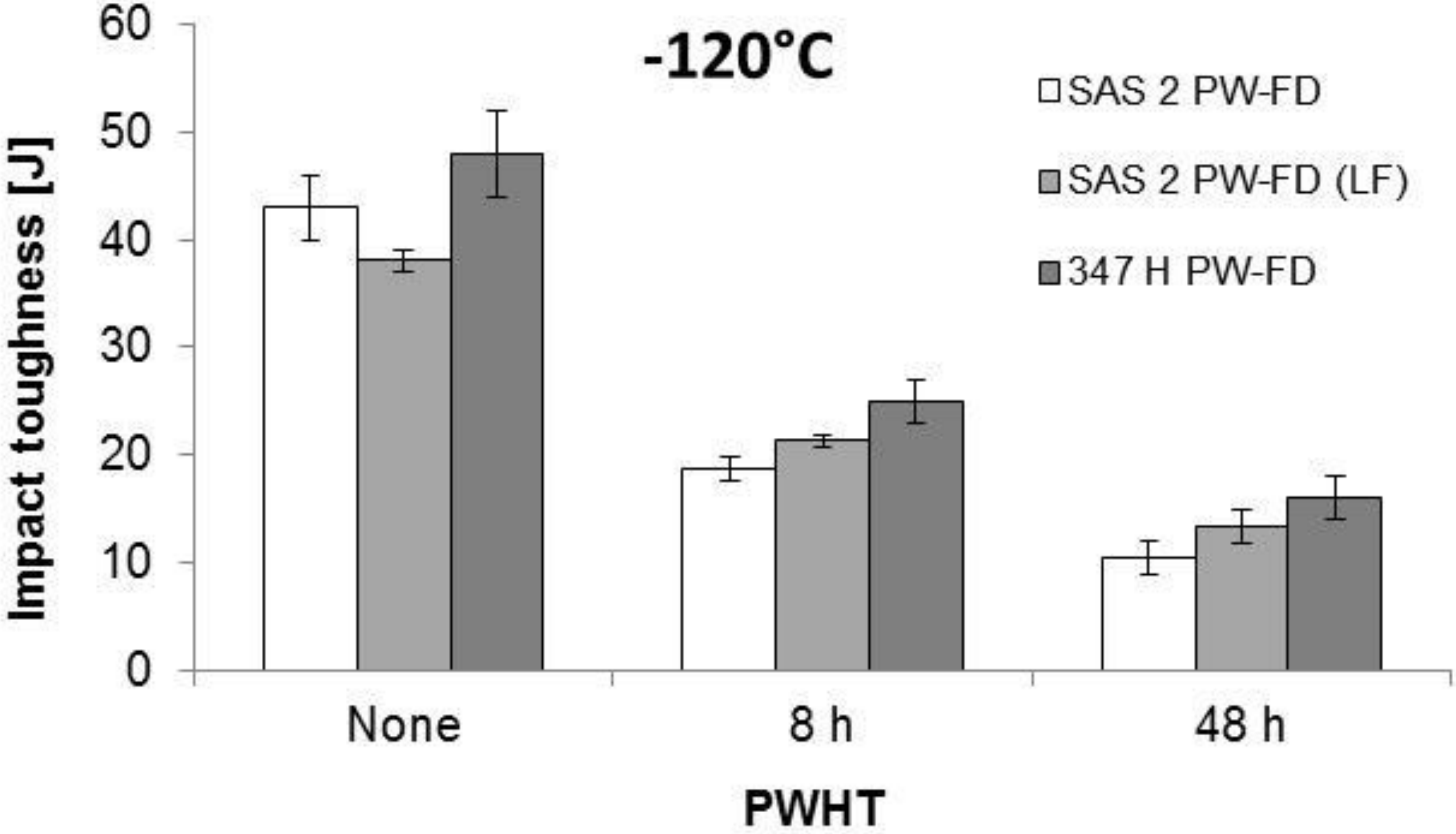
C	Si	Mn	Cr	Ni	Nb	Ferrite *
0.045	0.6	1.5	18.5	10.5	0.45	6

*** Ferrite measured with Fischer Ferrtscope MP30**

Comparison of the notched impact toughness

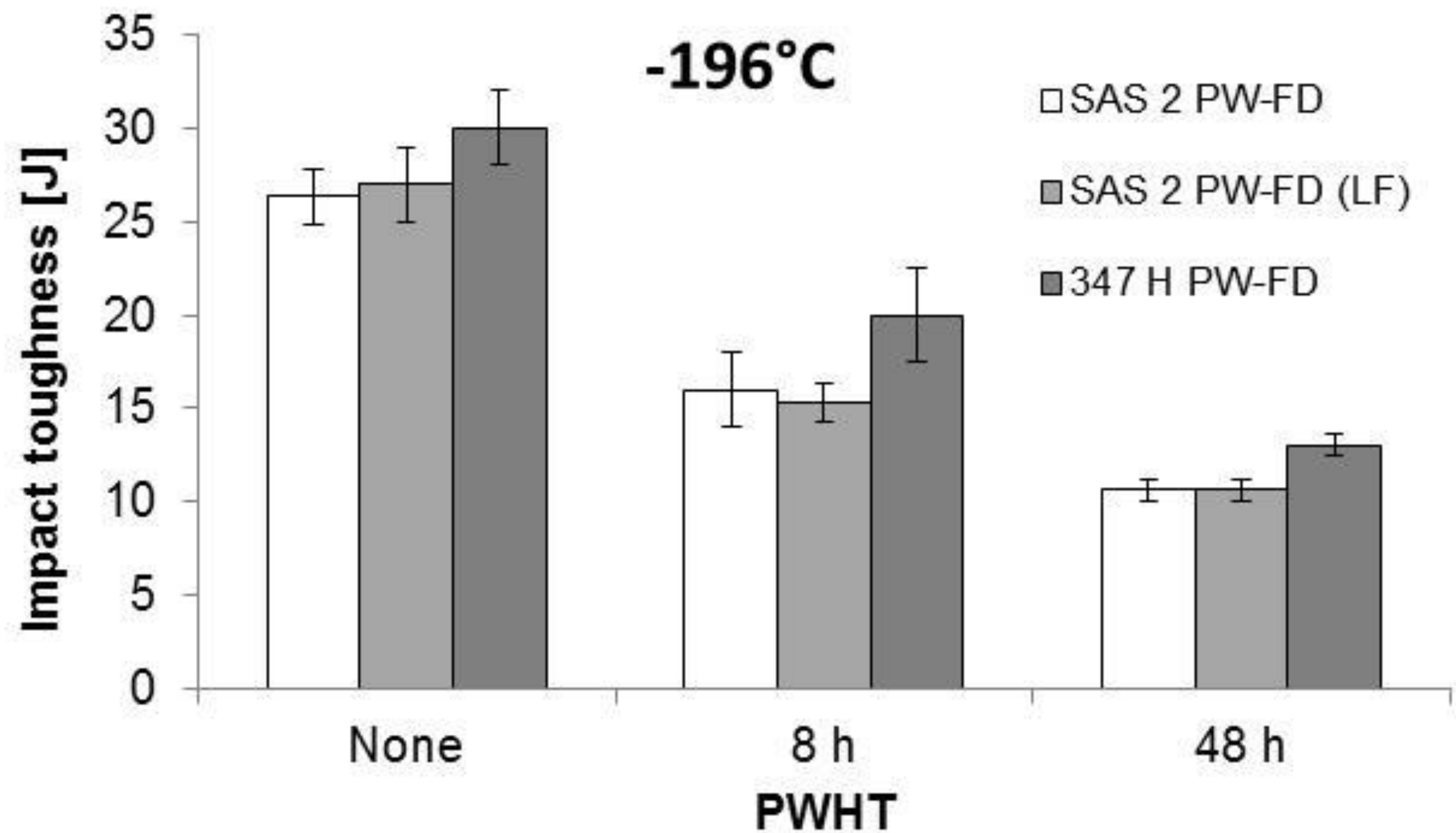


Comparison of the notched impact toughness



Comparison of the notched impact toughness

böhler welding
by voestalpine



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E 347L H-FD and E 309L H-FD “T0” type: targeted solution for cladding creep resistant steels

Typical values of all weld metal

Shielding gas: Ar + 18% CO_2

E 347L H-FD

C	Si	Mn	Cr	Ni	Nb	Ferrite
0.030	0.6	1.4	18.5	10.5	0.4	6

E 309L H-FD

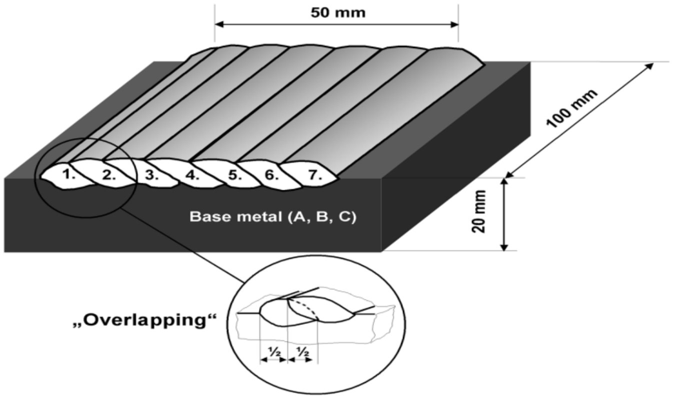
C	Si	Mn	Cr	Ni	Ferrite
0.030	0.6	1.3	22.8	12.5	14

Two-layer Cladding on base material 10CrMo 9 10 (ASTM A387 gr. 22)

Welding Parameter:

Interpass-Temperature.:	max. 150°C
Shielding gas:	Ar + 18% CO_2
Amperage:	230 – 240 A
Wire feed speed:	12 m/min
Overlapping:	~50%

1st Layer	E 309L H-FD	**2304880**
2nd Layer	E 347L H-FD	**Sample 6335**



Chemistry from the surface of the 1st and 2nd layer

	C	Si	Mn	Cr	Mo	Ni	Nb	Ferrite measured
1st layer	0.048	0.529	1.30	19.80	0.148	10.33	<0.004	8.9 FN
2nd layer	0.034	0.593	1.49	19.28	0.083	10.21	0.39	6.5- 7.5 FN

Undiluted chemistry from the wires

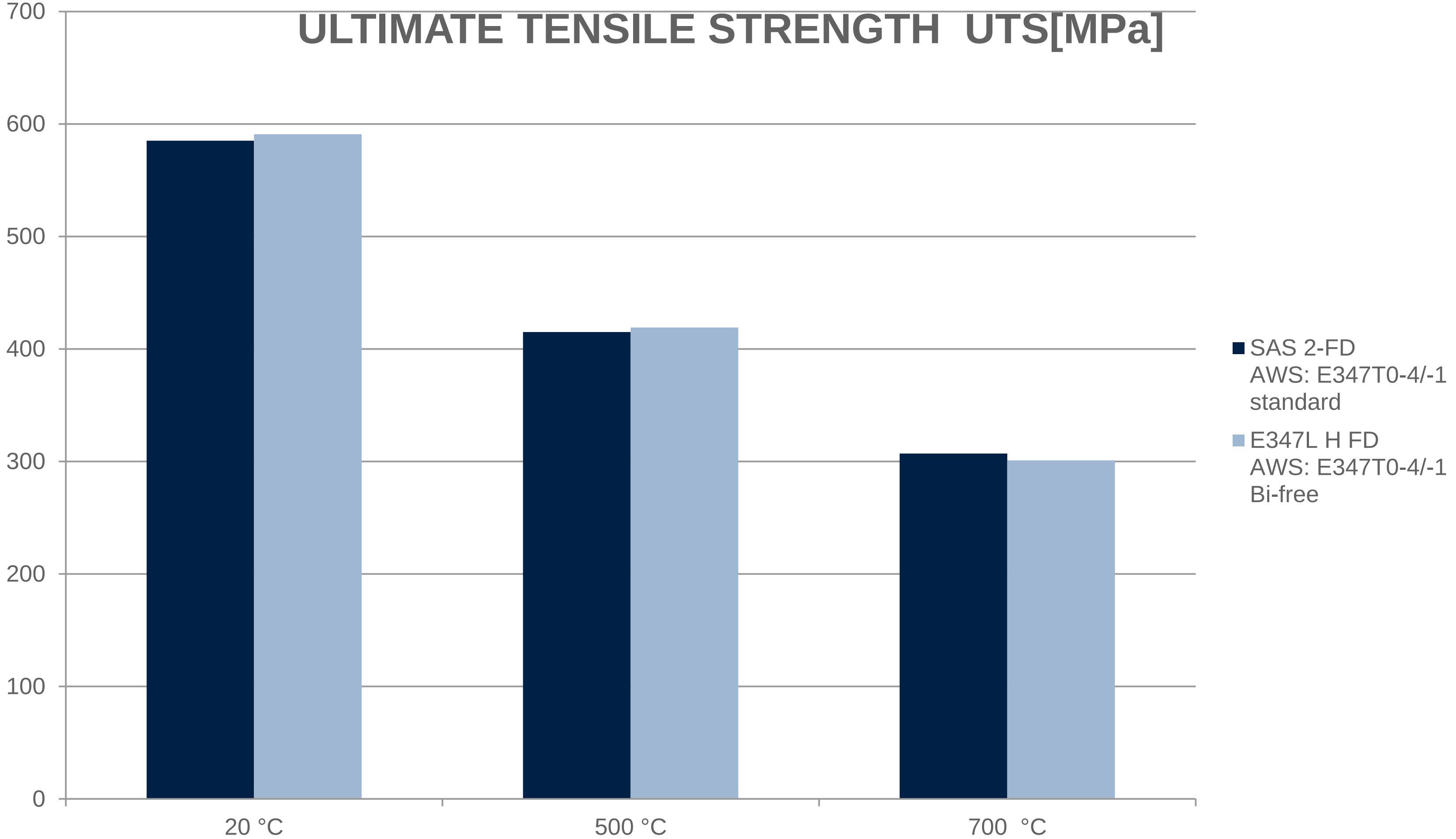
	C	Si	Mn	Cr	Mo	Ni	Nb	Ferrite measured
E 309L H-FD 2304880	0.034	0.579	1.36	23.13	0.041	12.62	0.012	14.8 FN
E 347L H-FD 6335	0.033	0.586	1.43	18.78	0.0392	10.24	0.439	6.7 FN

1st layer with E309L H FD

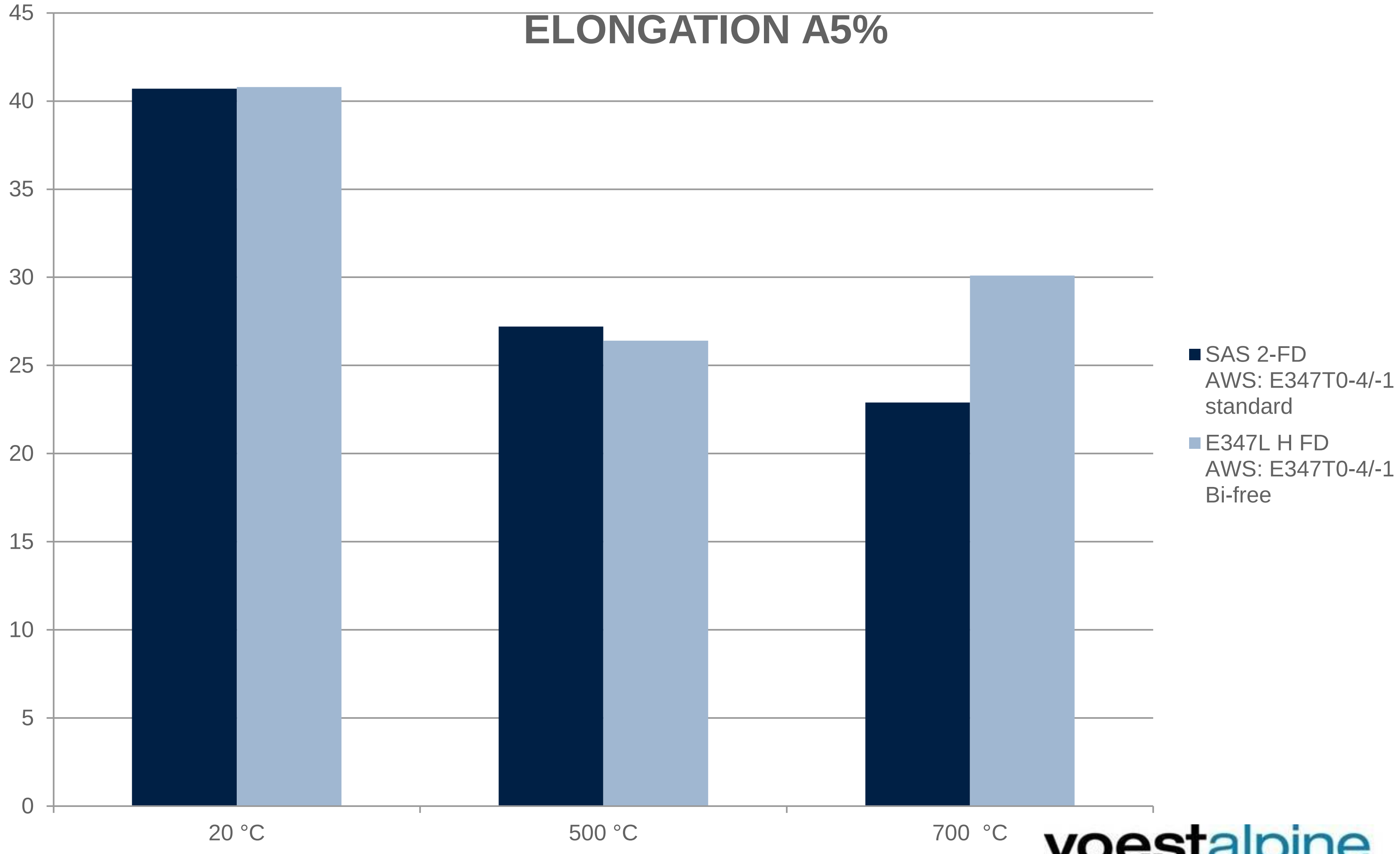
None Destructive Testing after the 1st layer

2nd layer with E347L H FD

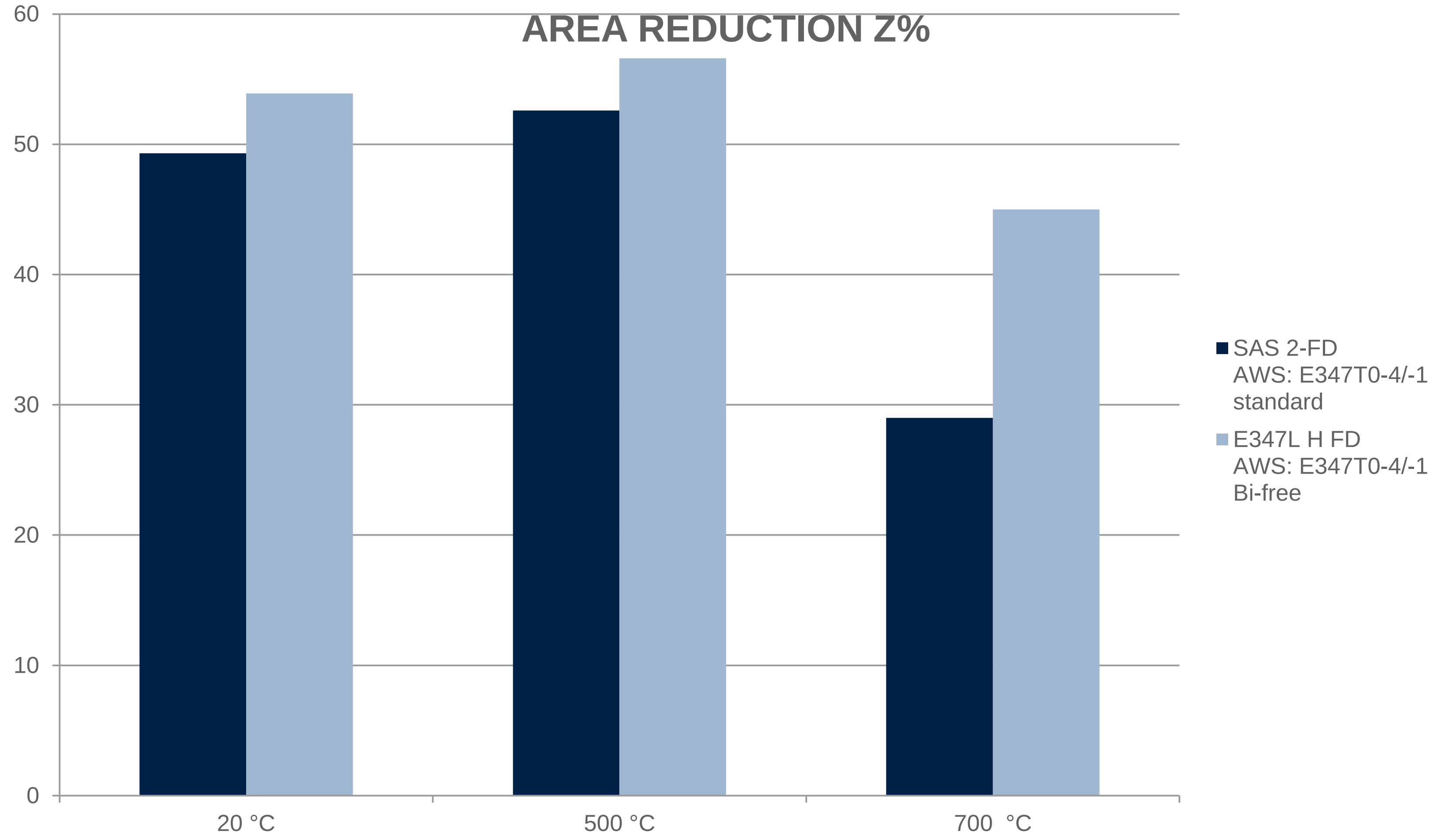
Hot Tensile Testing: all weld metal of alloy 347



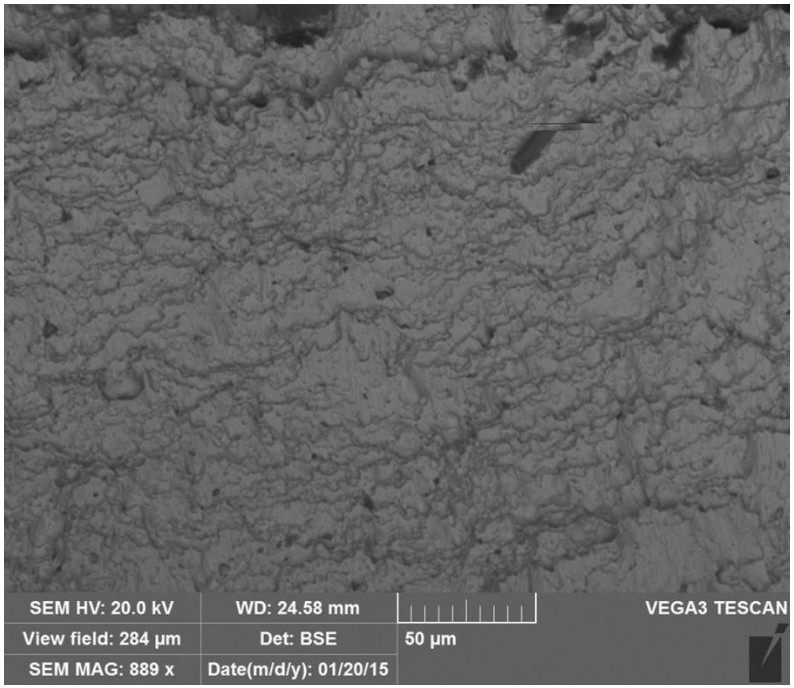
Hot Tensile Testing: all weld metal of alloy 347



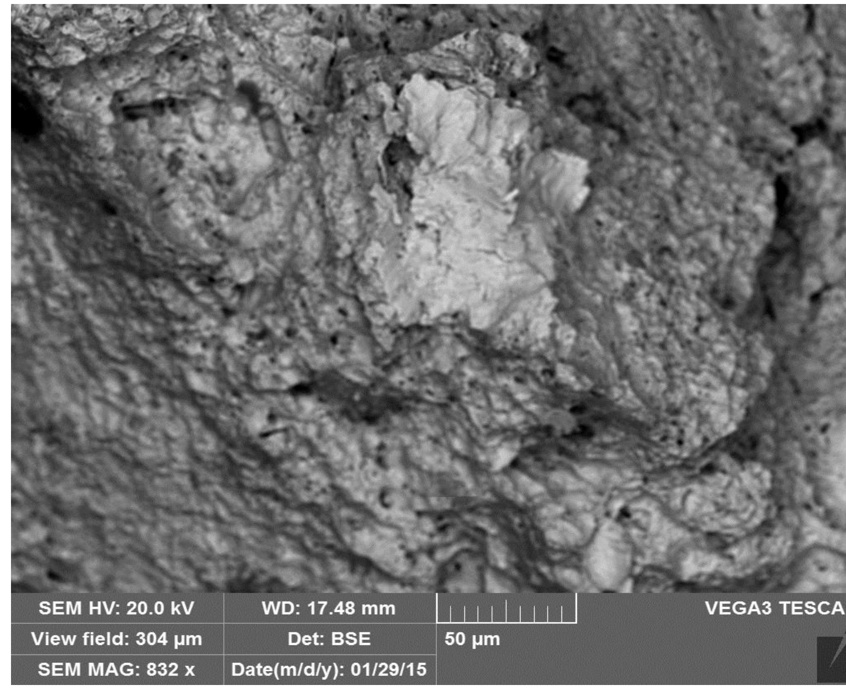
Hot Tensile Testing: all weld metal of alloy 347



347 type: Fracture Analysis – Hot Tensile 700 °C



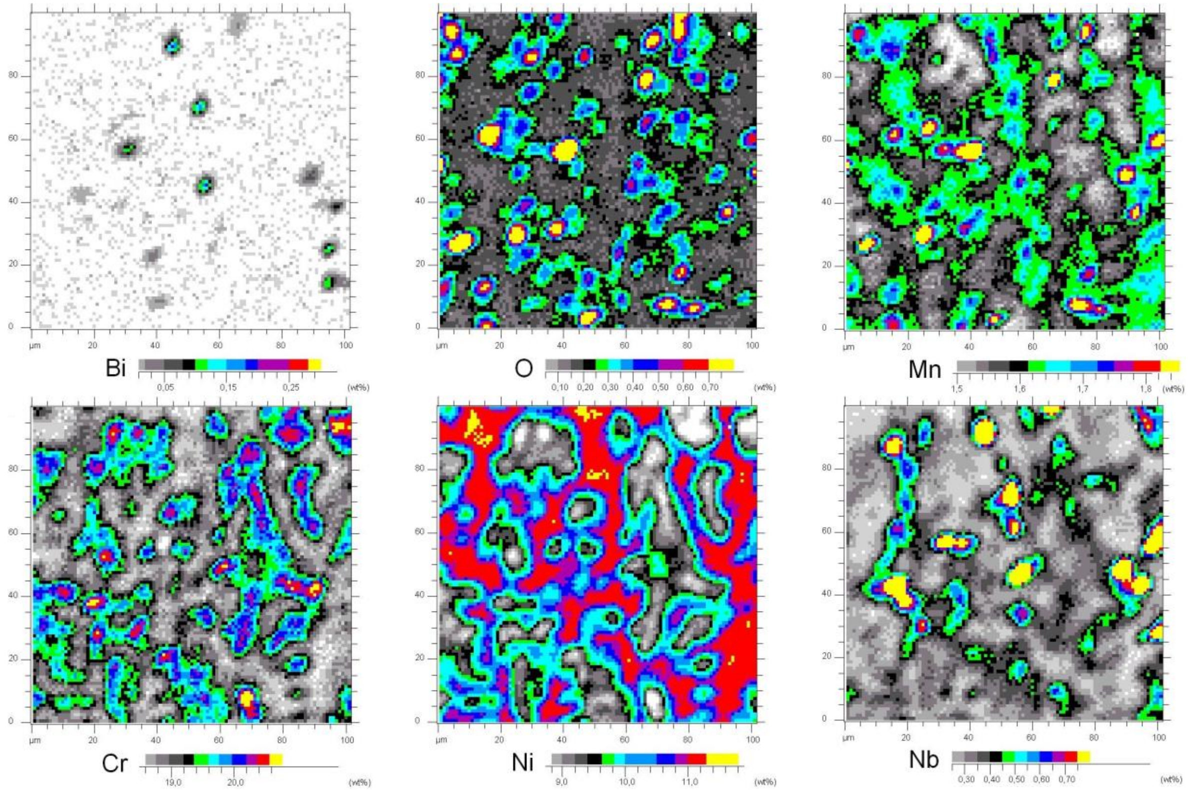
SAS 2-FD



E 347L H-FD

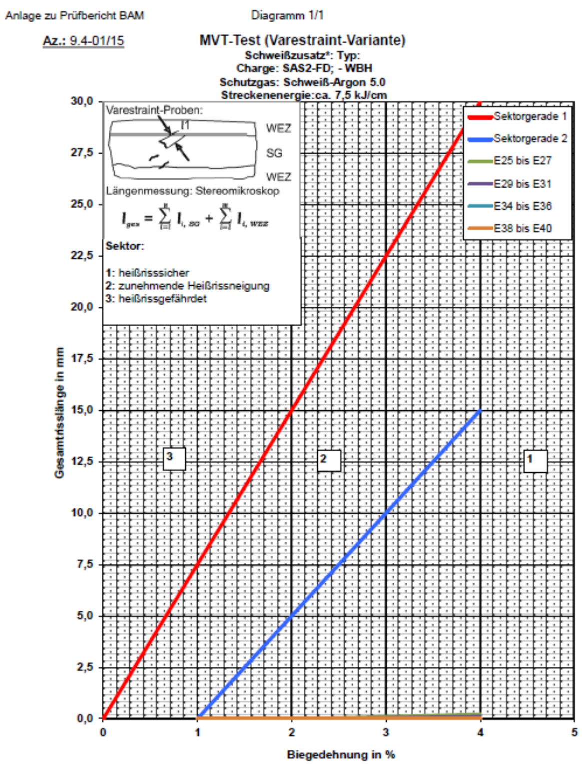
The amount of the spots with **„brittle fracture matrix“** in the SAS-2 FD **(with bismuth)** specimen **is slightly prevailing** than in the E 347L H-FD specimen

Element distribution in EPMA mapping of SAS 2-FD all-weld metal (conventional Bi-added FCW)



EPMA mapping shows that bismuth is present as particles and not as bismuth oxide Bi_2O_3.

Hot cracking test MVT



Proben-bez.	Video	5) S.-Daten	Prüfparameter: Proben-dicke [mm]	2) Biege-radius [mm]	Biege-dehnung [%]	Gesenk-geschw. [mm/s]	Schweißparameter: 3) Schweiß-strom [A]	3) Lichtbogen-spannung [V]	Schweiß-geschw. [cm/min]	Strecken-energie [kJ/cm]	Rissauswertung – Erstarrungs- u. Wiederaufschmelzrisse: Rissanzahl SG [-]	Gesamtriss-länge SG [mm]	Rissanzahl WEZ [-]	Gesamtriss-länge WEZ [mm]	4) DDC: Rissanzahl DDC [-]	Gesamtriss-länge DDC [mm]
E 25		0009		500	1	2,0	188,5	12,9	18	8,1	0	0	0	0	0	0
E 26		0005		250	2	2,0	188,5	13,3	18	8,4	0	0	0	0	0	0
E 27		0001		125	4	2,0	189,5	13,5	18	8,5	0	0	4	0,24	6	0,49
E 29		0010		500	1	2,0	188,5	12,9	18	8,1	0	0	0	0	0	0
E 30		0006		250	2	2,0	188,6	13,2	18	8,3	0	0	0	0	0	0
E 31		0002		125	4	2,0	189,1	13,4	18	8,4	0	0	2	0,13	1	0,40

Proben-bez.	Video	5) S.-Daten	Prüfparameter: Proben-dicke [mm]	Biege-radius [mm]	2) Biege-dehnung [%]	Gesenk-geschw. [mm/s]	Schweißparameter: 3) Schweiß-strom [A]	3) Lichtbogen-spannung [V]	Schweiß-geschw. [cm/min]	Strecken-energie [kJ/cm]	Rissauswertung – Erstarrungs- u. Wiederaufschmelzrisse: Rissanzahl SG [-]	Gesamtriss-länge SG [mm]	Rissanzahl WEZ [-]	Gesamtriss-länge WEZ [mm]	4) DDC: Rissanzahl DDC [-]	Gesamtriss-länge DDC [mm]
E 34		0011		500	1	2,0	188,4	12,7	18	8,0	0	0	0	0	0	0
E 35		0007		250	2	2,0	188,5	13,0	18	8,2	0	0	0	0	0	0
E 36		0003		125	4	2,0	189,0	13,1	18	8,3	0	0	0	0	0	0
E 38		0012		500	1	2,0	188,4	12,7	18	8,0	0	0	0	0	0	0
E 39		0008		250	2	2,0	188,5	12,9	18	8,1	0	0	0	0	0	0
E 40		0004		125	4	2,0	188,8	13,1	18	8,2	0	0	0	0	0	0

No cracks on E 347L H-FD (Bi-free) samples;
(PWHT: 705°C/40h)

böhler welding by voestalpine

voestalpine ONE STEP AHEAD.

E 308 H-FD & E 308 H PW-FD

Shielding gas: Ar + 18% CO_2

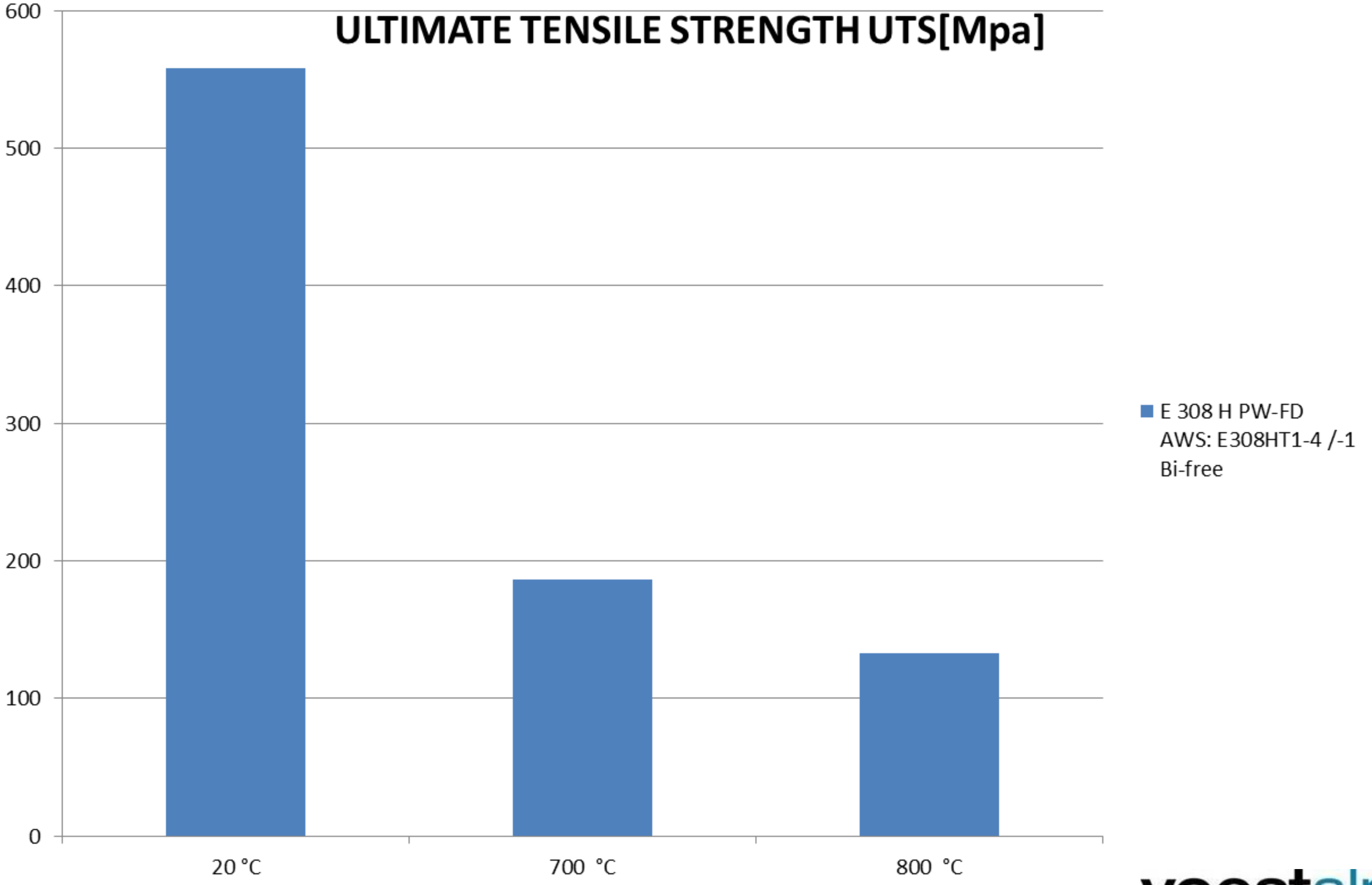
	C	Si	Mn	Cr	Ni	FN**
	0.05	**0.6**	**1.3**	**19.4**	**10.4**	**6**

* measured with Fischer Feritscope MP 30

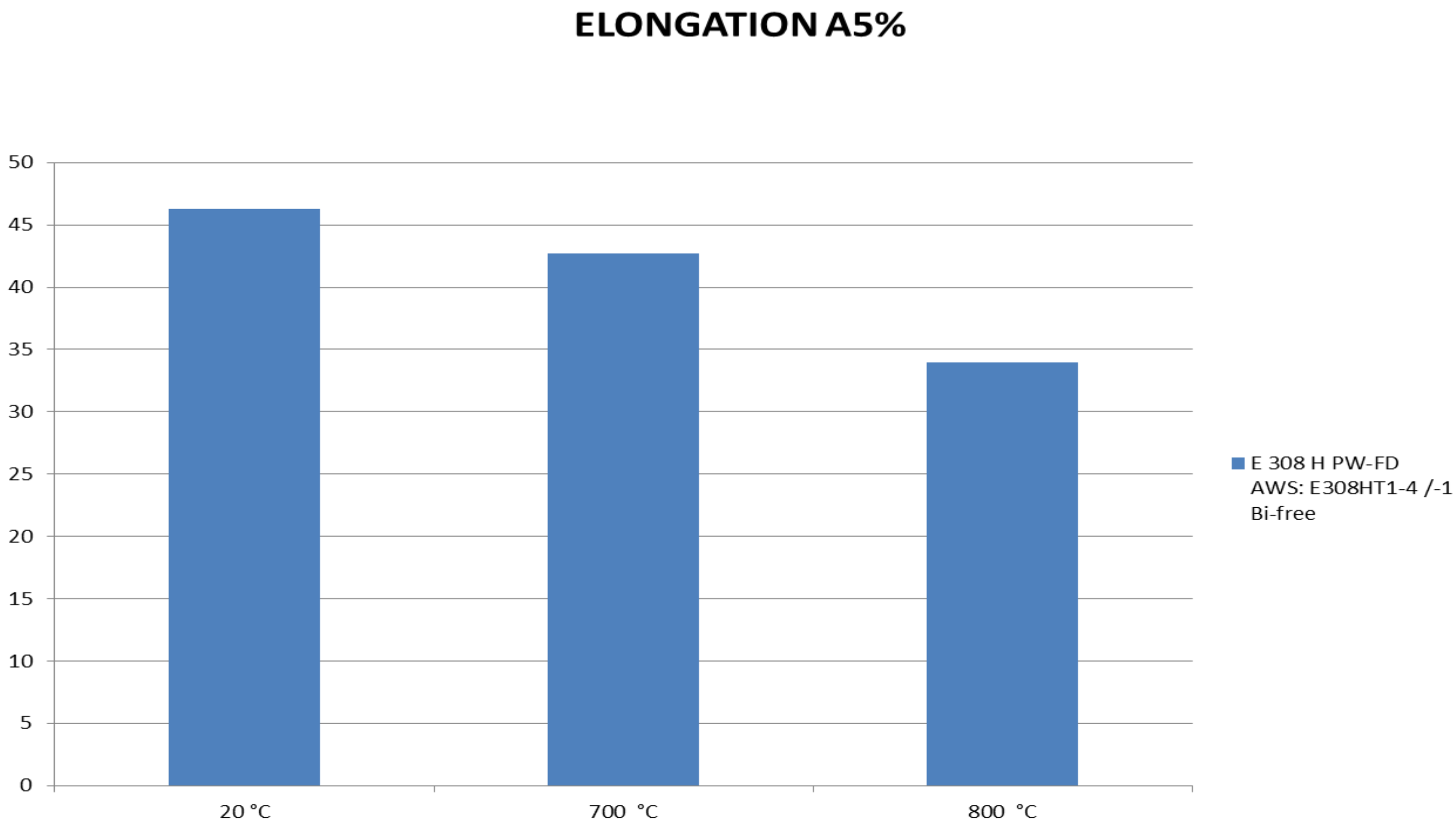
	Tensile Test				Impact Toughness ISO-V [J]
	$Rp_{0.2}$ [N/mm²]	R_m [N/mm²]	A_5 [%]	Z [%]	Test temperature +20 [°C]
E 308 H-FD	355	555	55	60	94 90 87
E 308 H PW-FD	373	558	46.3	47.2	106 108 90

[°C]	Lateral expansion +20
E 308 H-FD	1.51 1.48 1.43
E 308 H PW-FD	1.69 1.73 1.60

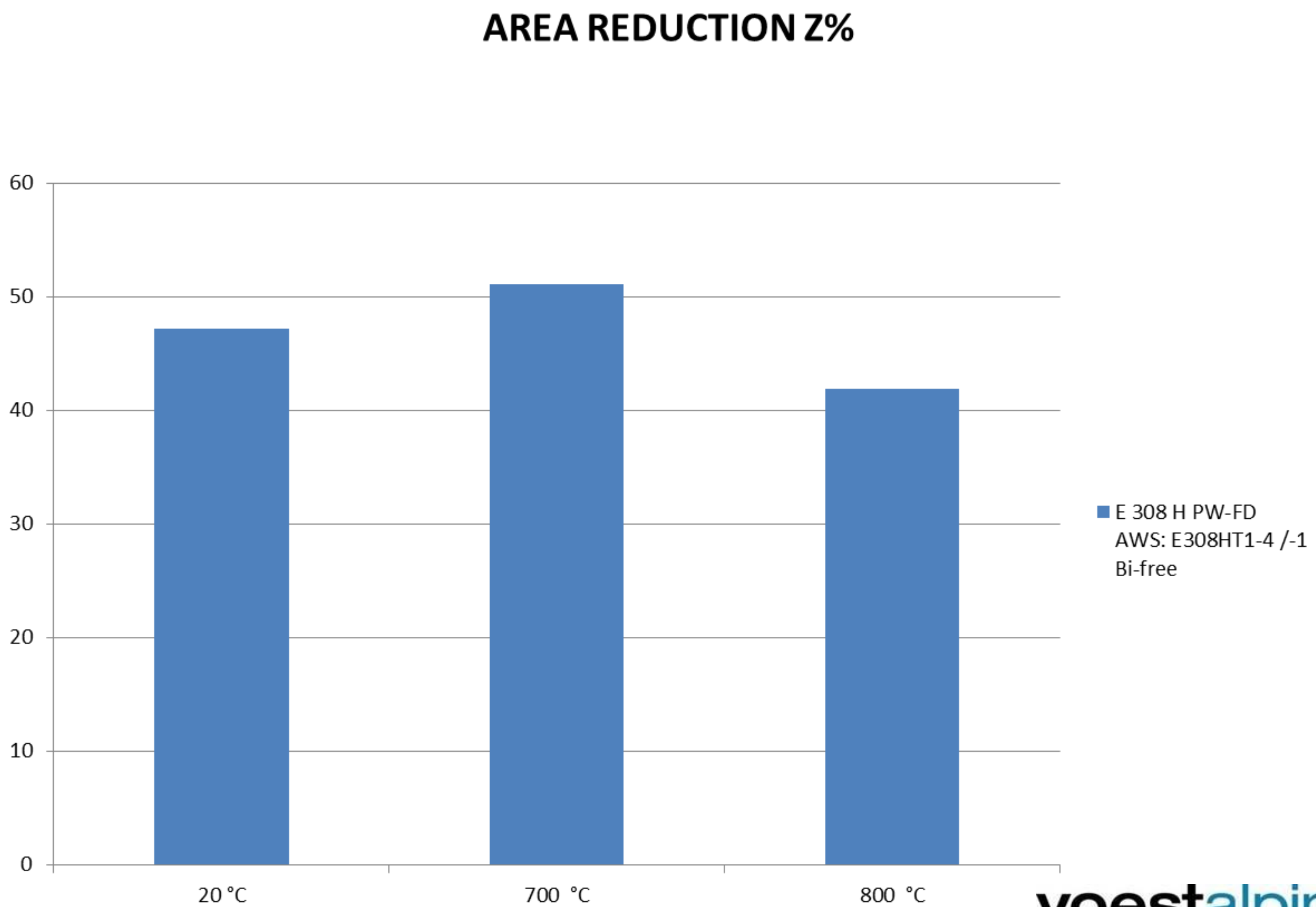
E 308 H PW-FD
All Weld Metal Tensile Tests 1/3



E 308 H PW-FD
All Weld Metal Tensile Tests 2/3



E 308 H PW-FD
All Weld Metal Tensile Tests 3/3



Conclusion

- High Temperature ductility loss/ cracking sensitivity is due to the **segregation of elemental bismuth at grain boundary (not bismuth oxyde)**
- Comparison of new **bismuth-free flux cored wires** for joining and overlay welding to conventional wires have been shown
- Bismuth-free wires showed **improved resistance to embrittlement** after PWHT at 700°C and **higher impact toughness**
- Hot tensile tests confirmed significantly **higher elongation** values for the bismuth-free wires and showed **no cracks in MVT tests**
- **Welding and slag removal is equal** to the standard wires

Appendix 5

Stainless steel bundle failure

(M. Poldi)

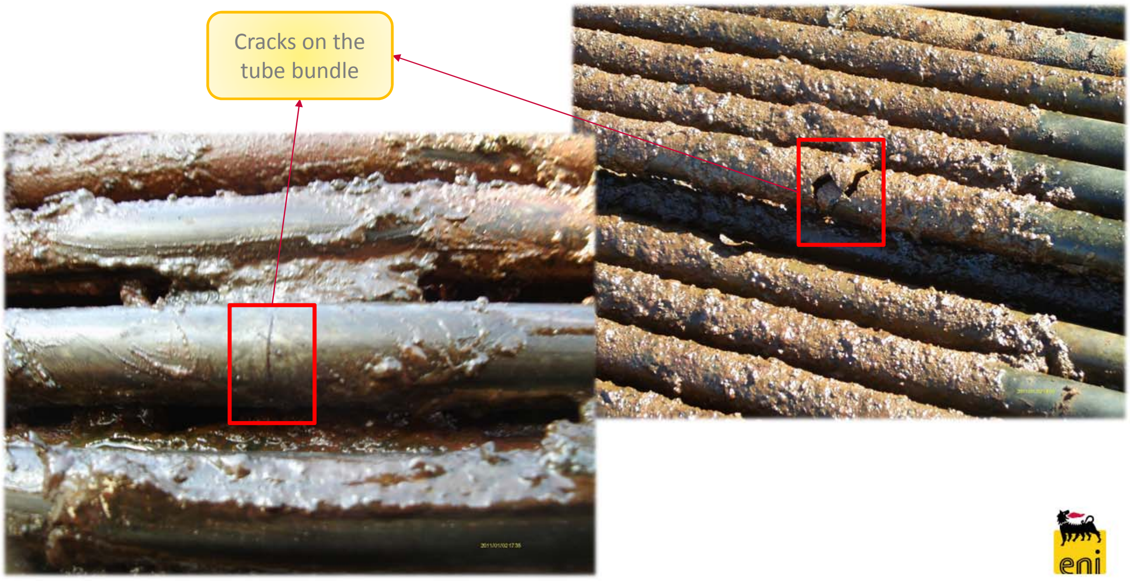
Hydrocarbon reboiler failure

April 2017

Hydrocarbon reboiler failure– Data and event list

- Heat exchanger description:
  - Tube side: heating medium mineral oil.
  - Shell side: light condensate.
  - Operative pressure: 18.5 barg.
  - Operative temperature: 223°C.
  - Tube material: SA213 -TP316L (SML5).
- Events:
  - Change of Shell side fluid from light condensate to light oil.
  - The light oil could carry traces of wet Cl.
  - Series of three unplanned SD.
- Failure:
  - After one month from the fluid switch, cracks and rupture of different tubes has been observed.
  - Preliminary RCA identifies SCC from Cl the rupture mechanism.

Hydrocarbon reboiler failure – Failed surfaces



Hydrocarbon reboiler failure– Failed hypothesis bullet points

I. Stress Corrosion Cracking brought the component to rupture in **about a month.**

II. Without the unplanned events, the heat exchanger should be able to work at regime without SCC initiation even with a fluid (light oil), different from the project one and with the presence of wet Cl.

III. The corrosion mechanism was active **only during transitional phases** (the three unplanned SD events).

Appendix 6

Cracks in dissimilar welds at primary reformer outlet

(Matthias Gierlinger)

Cracks in dissimilar welds at reformer outlet - Linz Ammonia plant

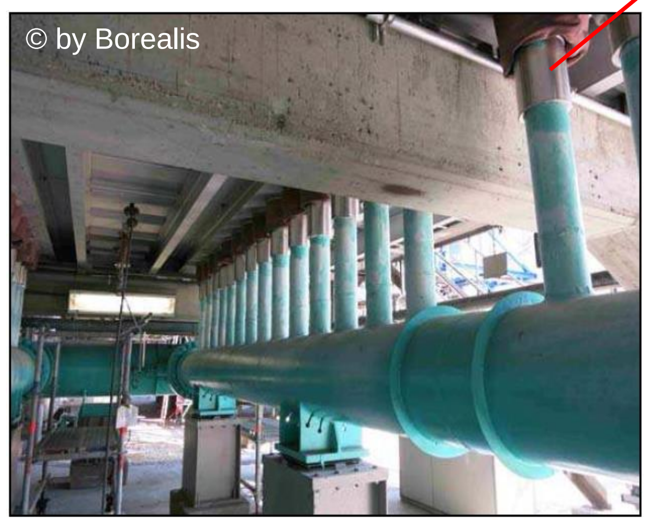
Matthias Gierlinger
(matthias.gierlinger@borealisgroup.com)

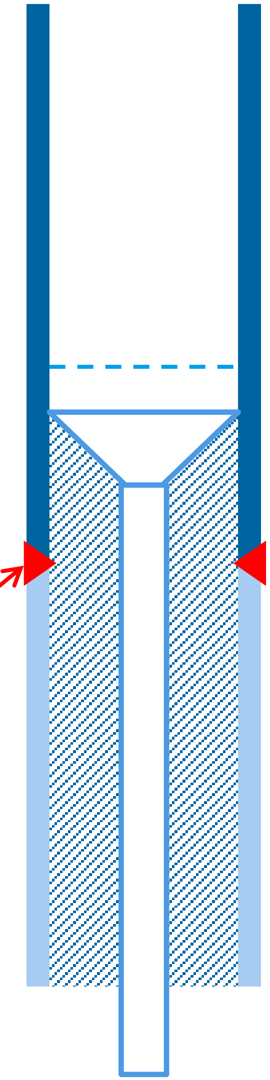
Borealis Innotech Process Technology
13.04.2016
EFC WP15 Spring Meeting

BOREALIS
Keep Discovering

History of steam reformer O-201 in Linz

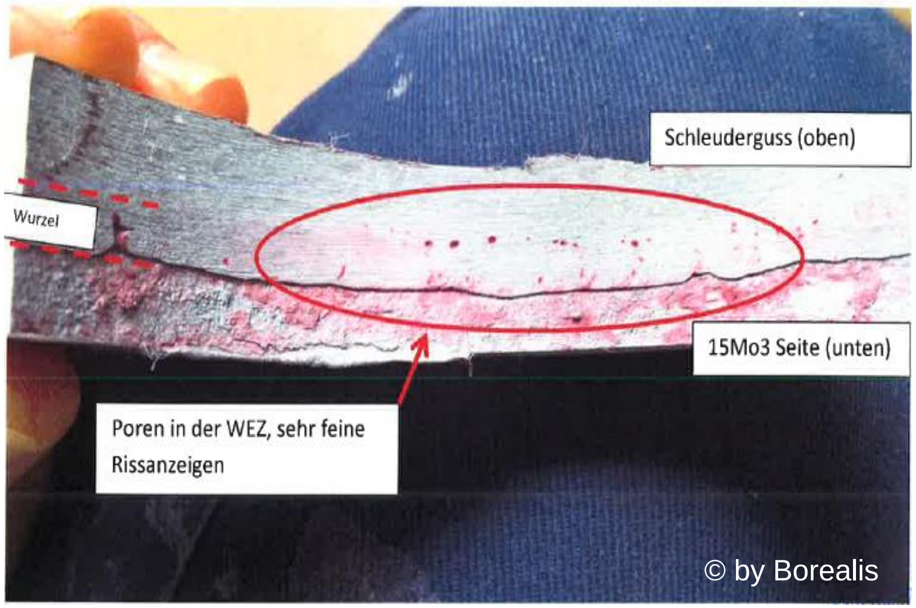
- Commissioning in 1974
- 258 reformer tubes and six bottom collectors; Uhde design
- First leakage reported in 1989, after ~15 years in operation
- Total record of four leakages
- Implementation of NDT program (UT) in 1997
- Repairs and/or change of tubes in SD/TA ever since
- 2016 repair of 17 reformer tubes in SD and ~ 70 with significant NDT-indications





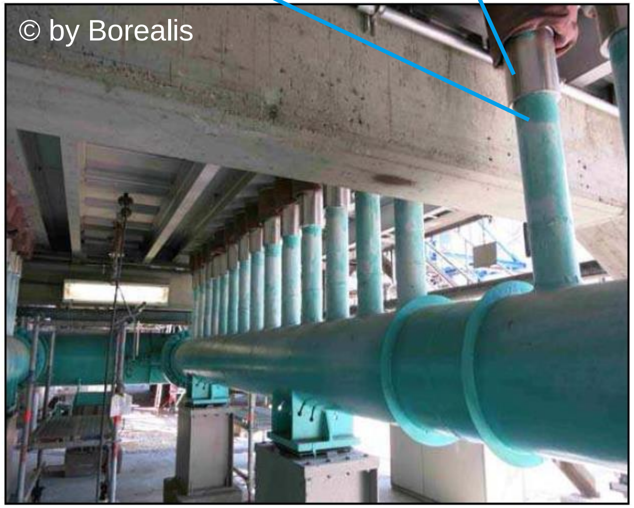
Damage description

- Crack indications between weld metal (~Inconel 82) and 15Mo3, max. depth 1,5mm
- Pores/small crack indications on weld metal and on spin cast material 36X

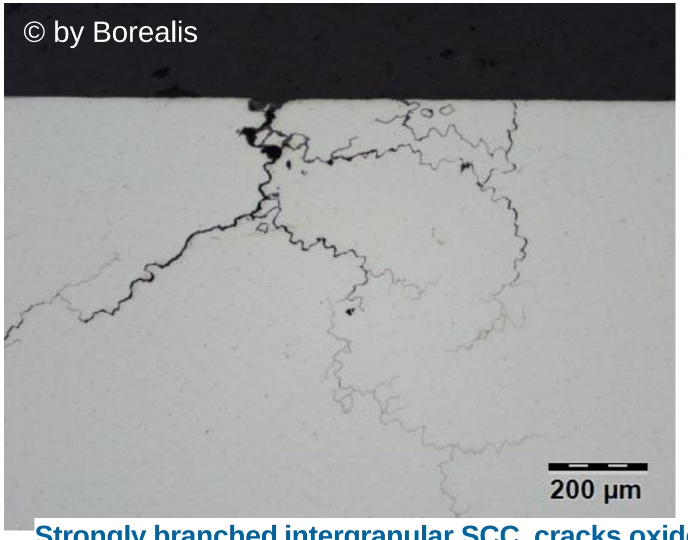


Inner surface of removed weld joint with UT-indications after PT, 15Mo3 towards bottom, 36X towards top of picture

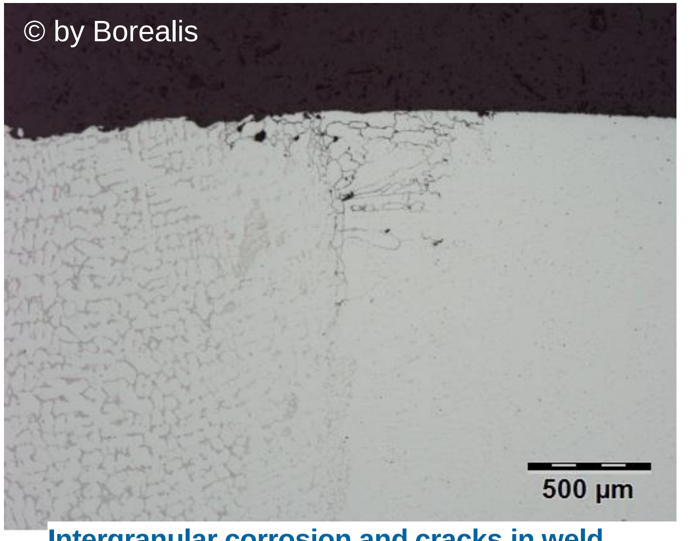
Materials: 36X, Inconel82, 15Mo3
Pressure: >30bar
Media: Steam, CO/CO_2, CH_4, H_2
Metal Temperatures:
- ~360°C on outer wall at defect
- ~230°C on outer wall outside insulation below defect



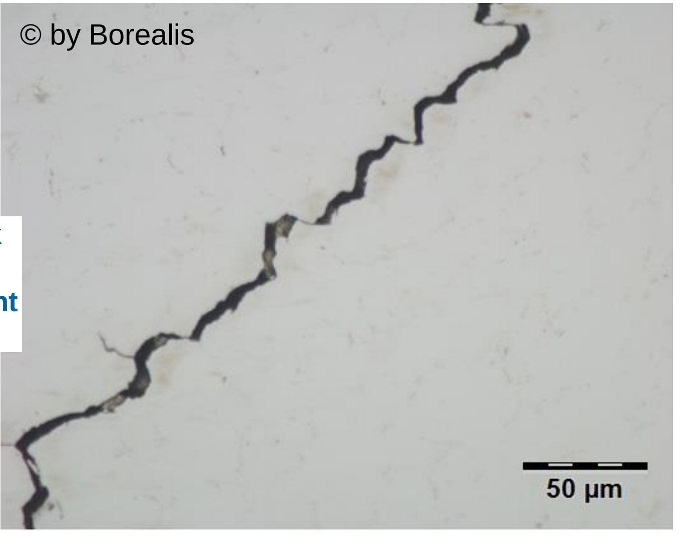
Stress corrosion cracking on stainless side



Strongly branched intergranular SCC, cracks oxide filled (grey), some crack flanks parallel opened (black)



Intergranular corrosion and cracks in weld metal (right) next to 36X base metal (left), some intergranular attack also in 36X base metal, depth ~0,8mm



Parallel opened crack flanks indicating influence of significant tensile stress

Process side shown in top side of pictures

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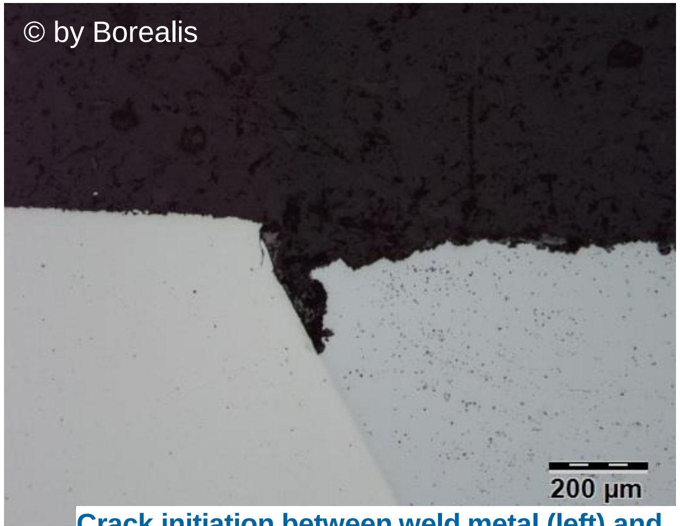
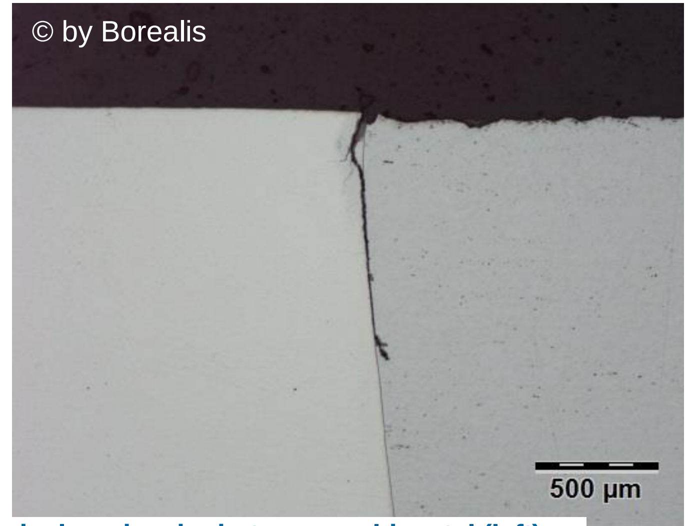
General corrosion and cracks on 15Mo3-side

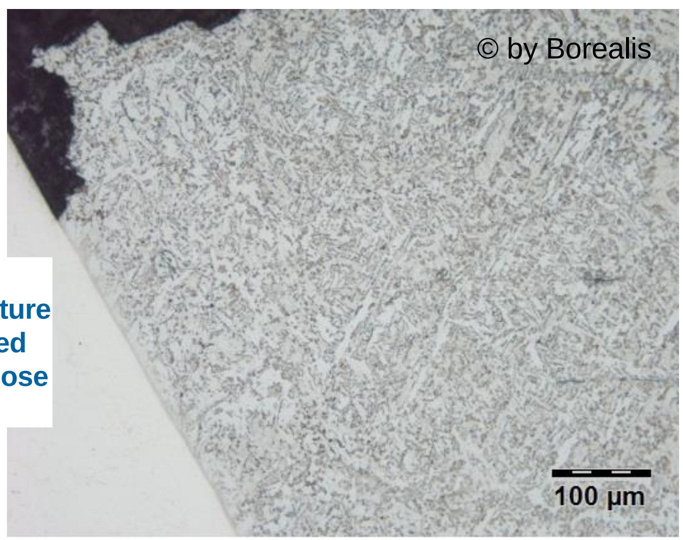


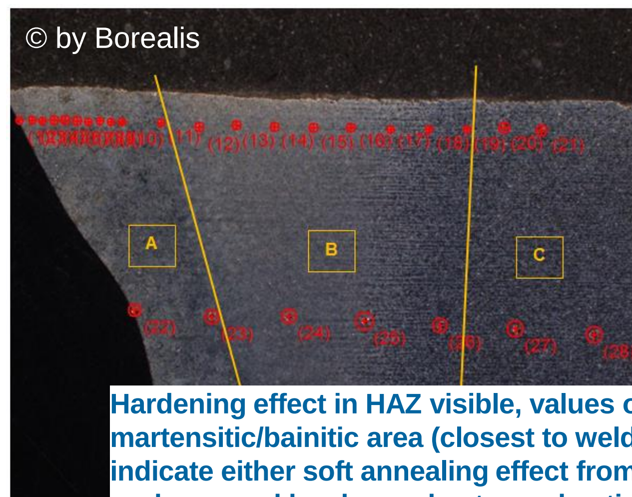
Crack initiation between weld metal (left) and 15Mo3 base metal (right), depth ~300µm, general corrosion on 15Mo3 side



Crack along border between weld metal (left) and 15Mo3 base metal (right), depth ~1mm

Martensitic/ Bainitic structure in heat affected zone (HAZ) close to weld metal





Hardening effect in HAZ visible, values of ~190HV in martensitic/bainitic area (closest to weld metal, area A) indicate either soft annealing effect from service conditions or decreased hardness due to pre heating for welding, hardness of unaffected base metal (area C) is ~160HV

Process side shown in top side of pictures

Failure mechanism

- The likeliest failure root cause is identified as condensation at the welds leading to:
  - carbonic acid corrosion with partial hydrogen cracking on the 15Mo3 side of the weld
  - as well as stress corrosion cracking (SCC) from accumulation of process impurities in the stainless materials (weld metal and 36X close to the weld).
- During the carbonic acid corrosion reaction hydrogen is released and partly diffusing into the material. It is assumed that this can lead to embrittlement when lowering the temperature.
- Crack propagation is expected mainly during shut down due to the induced tensile load during the contraction of the materials and the embrittling effect at decreased temperature. During normal operation slow crack propagation can be assumed.

Literature:

This failure mechanism has been observed already in the past in reformer plants with the Uhde-design [1, 2, 3]

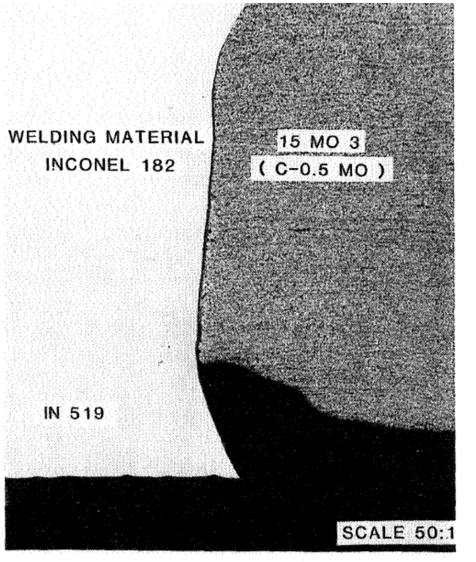


Figure 8. Crack starting from corrosion groove section of Figure 7.

Morphology of carbonic acid corrosion attack in the HAZ of the 15Mo3 side and crack propagation along the weld interface [1] , the same morphology was found in Borealis' Linz site

1. Osama El Ganainy, *Failure of Dissimilar Metals Weld in Reformer Tubes*, AIChE – Safety in Ammonia Plants & related Facilities Symposium, 1984
2. G. Matthew Webb and W.K. Taylor, *Reformer Tubes: Not a Commodity*, AIChE – Safety in Ammonia Plants & related Facilities Symposium, 2005
3. Andrew Walker and Neil Mackenzie, *Dissimilar Weld Cracking and Repairs on Primary Reformer Exit Headers*, AIChE – Safety in Ammonia Plants & related Facilities Symposium, 1995

BOREALIS

Leak before break evaluation

- For safety reasons the leak before break scenario had to be verified.
- Cases in literature (slide 6) experienced leak before break.
- Leakages have already occurred at Borealis' Linz site in the past. Leak before break has been observed.
- Crack propagation is expected mainly during shut downs.
- The low hardness values of the HAZ on the 15Mo3 side indicate a low risk for pronounced hydrogen cracking and do not indicate a risk of brittle failure.

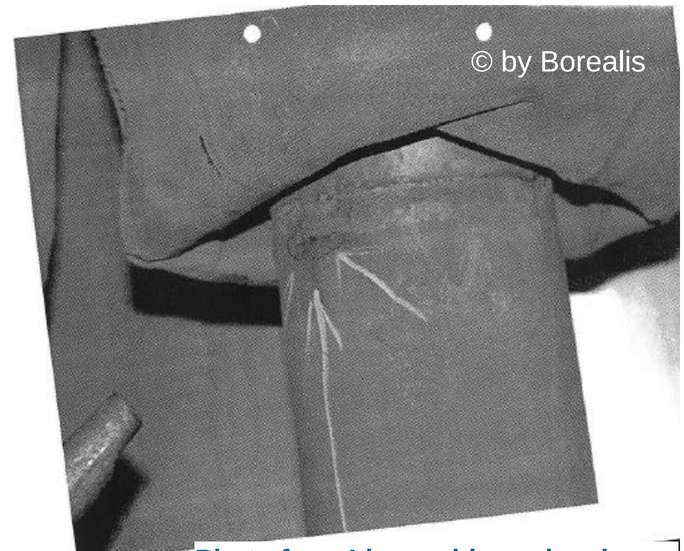


Photo from Linz archives showing leak at dissimilar weld with N2-flushing nozzle installed.

Conclusions

- Failure mechanism is believed to be understood.
- Inspection and repair actions have been defined.
- Improved welding procedure still needs to be defined.

Appendix 7

Failure of stripper feed/bottom heat exchanger SS304L tubes in a naphtha hydrotreatment unit

(F. Dubois)

Axens
IFP Group Technologies

EFC WP15 Corrosion in Refinery
Frankfurt, 13th April 2017

Failure of stripper feed/bottom HE 304L tubes in a NHT unit

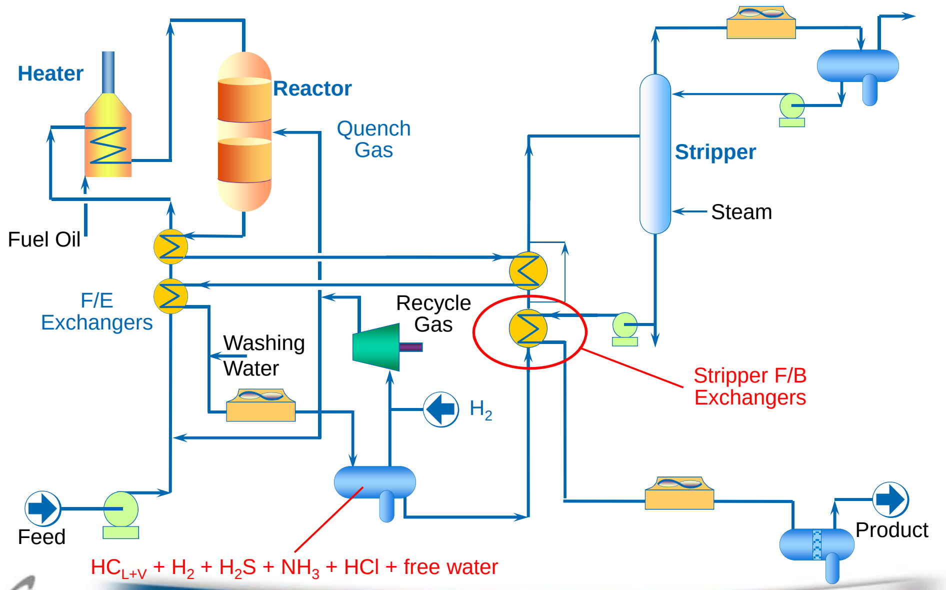
François Dubois

NHT unit

- ***Naphtha hydrotreatment NHT***
- ***Hydrotreatment Reactions***
  - ***Catalytic reaction in presence of H2***
  - ***Sulfur & Nitrogen removal from Naphtha cut → by-products are H2S & NH3***
  - ***Chloride compounds are hydrotreated to HCl***
- ***Intermittent washing of reactor effluent air cooler (REAC) with water injection***
  - ***Dissolution of precipitated NH4HS solid salts***
- ***3 phase separation***
  - ***Liquid HC is heated in Stripper Feed/Bottom heat exchanger***
  - ***Warm liquid HC is sent to the stripper***
- ***Stripper***
  - ***Degazing H2S and NH3 from Desulfurized Naphtha product***

Axens IFP Group Technologies

Generic NHT Process Flow Diagram



Stripper Feed / Bottom Heat Exchanger

- ***Original Material of Construction***
  - ***Carbon steel with resistance to wet H2S cracking (SSC and HIC)***
- ***Water is separated in the cold separator drum upstream stripper F/B HE***
  - ***Separator designed for the decantation of droplets above 50 µm***
  - ***Carry over of smaller water droplets in the liquid HC phase***
- ***Sour water is vaporized in the 1st Stripper F/B HE***
  - ***No HCl – Mild corrosive conditions with life time > 5 years for tube bundle***
  - ***HCl presence – Corrosive conditions with reduced lifetime < 2 ½ years***

Stripper Feed / Bottom Heat Exchanger

- *Design/Operating conditions*
  - *Tdesign = 49°C to 134°C*
  - *P = 12bara*
  - *Sulfur@design (H2S) = 1%*
  - *Liquid / Mixed phase hydrocarbon at water dew point*
  - *Water droplets carry-over from cold HP 3ph separator drum*
  - *Chloride in NHT unit feedstock < 0.5 ppm*

Change of tube material

- *CS tube bundle was changed several times with an identical material (CS HIC resistant) due to accelerated corrosion*
  - *Start-up : 2009*
  - *Turn-around and 1st change of tubes : 2012*
  - *Turn-around and 2nd change of tubes : 2014*
- *Decision was made to switch tube material to stainless steel*
  - *Selected grade for the new Feed/Bottom HE Tubes : SS 304L*
- *Change of tube material march 2016*

→ *Failure of Tube bundle after 1 week operation !*

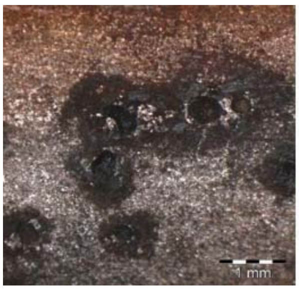
→ *Several other failures in following months*

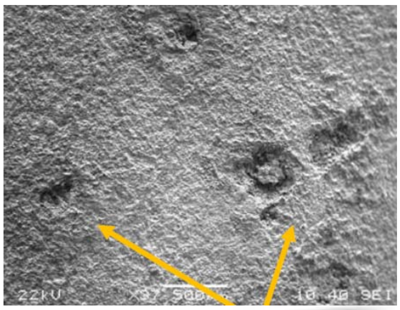
SS 304L tubes failure analyses

- *General aspect*

SS 304L tubes failure analyses

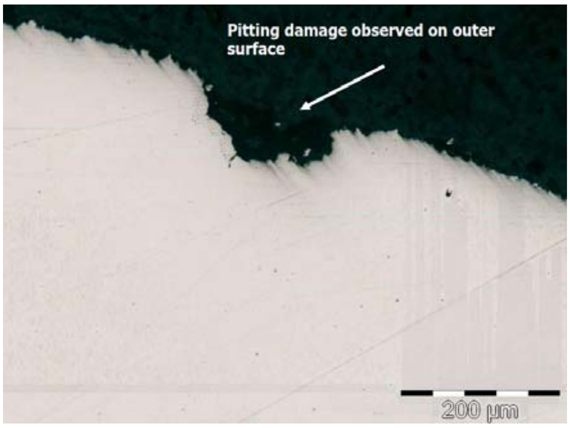
- *Pits at tube outer surface*





SS 304L tubes failure analyses

- ***Pits at tube outer surface***

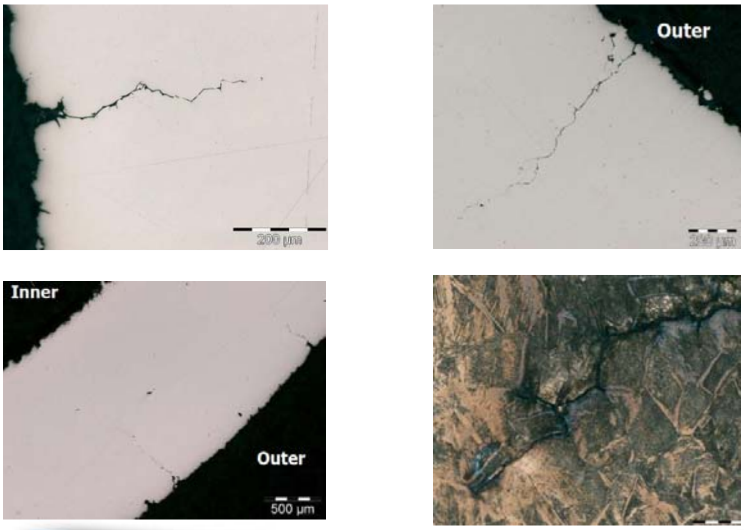


SS 304L tubes failure analyses

- ***Cracks***

SS 304L tubes failure analyses

- ***Cracks : intergranular***



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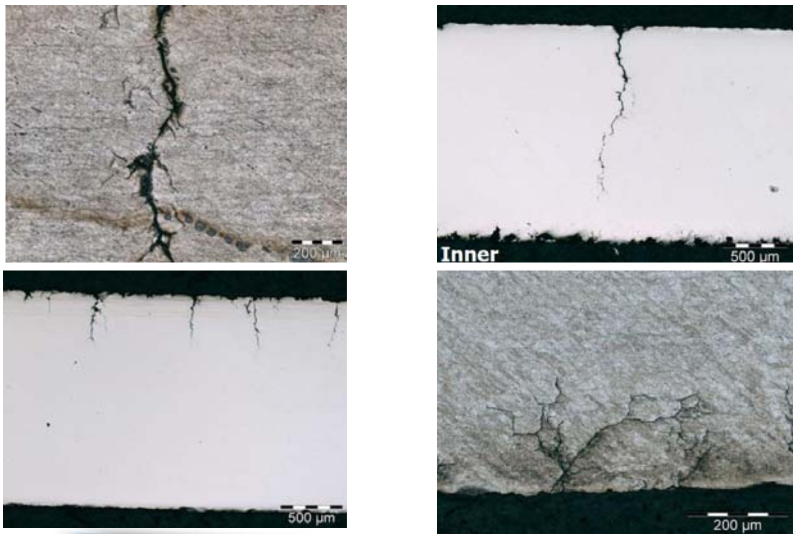
SS 304L tubes failure analyses

- ***Cracks : transgranular***



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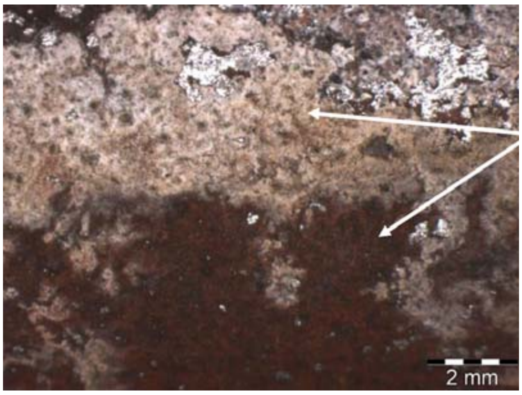
SS 304L tubes failure analyses

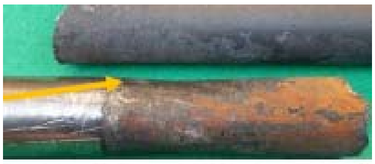
- *Surface deposits*

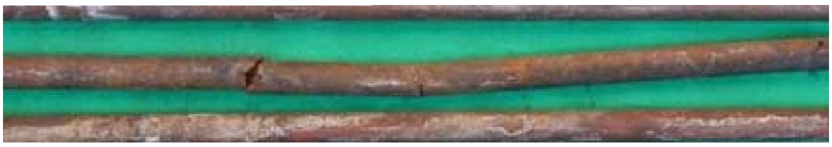


- *Sulfur and chlorides detected*

SS 304L tubes failure analyses

- *Mechanical degradation with plastic deformation and martensite formation*





- *Hardness measurements a little high but still within the range for SS 304L material : 200HV10*

Findings

- ***Switch back to carbon steel bundle that suffers only rapid generalized corrosion***
- ***Several mechanisms contributed to the failure of 304L***
  - ***Evidence of CL-SCC, wet H2S-SCC, pits***
- ***Exchange of tube material metallurgy from CS to SS without proper design review***
  - ***Differential thermal dilatation and constrains during operation***
  - ***Presence of chloride ions in wet H2S environment with water vaporization***
- ***Alternate material (Ni-Cr-Mo) to be considered in this very corrosive environment***

Axens IFP Group Technologies

Thank you

- ***And thanks to*** MEGCHEM ***who performed the analyses***

Axens IFP Group Technologies

Appendix 8

New corrosion inhibitors for cooling water systems

(V. Bour-Beucler)

New High Charge Polymer to improve corrosion inhibitor performance, TCO and optimize CW cycle of concentration

Eurocorr 2017

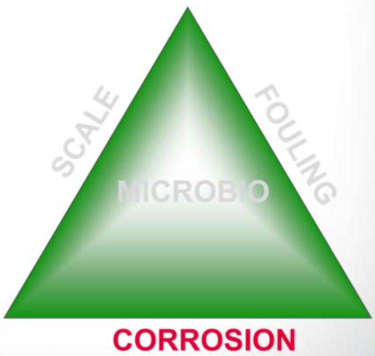
Frankfurt Spring Meeting

Valerie Bour Beucler

NALCO Champion
An Ecolab Company

Cooling water system successful management

- Cooling water successfull management
  - A good equilibrium between corrosion, scaling and MIC



Regulation and cooling system

- **Legionella Control and regulation**
  - Minimize the risk of legionella
- **Biocidal Product Directive / Regulation**
  - harmonise the European market for biocidal products and their active substances.
- **REACH (European Commity Regulation on Chemical and their safe Use (EC 1907/2006)**
  - It deals the Registration Evaluation Authorisation and Restriction of Chemical substances.
- **The Future**
  - **Less non oxidizing biocides**
  - **More oxidizing biocide but with AOX control**
    - **Chlorine dioxide (ClO_2), a good alternative**

NALCO Champion
An Ecolab Company

Taking Energy Further™ 3

Cooling systems traditional treatment

- Recirculating cooling system treatment with pH control
  - Corrosion inhibitors
    - Anodic and cathodic
    - Orthophosphates as anodic corrosion inhibitor
  - Polymer
    - To reduce tricalcium phosphate (TCP) scaling with phosphate dispersion
    - TCP will depend of pH, stress conditions, température, ortho-phosphate, calcium level and polymer performance and dosage.
    - Disperse Al and iron
    - Consumption with SS, bleach…

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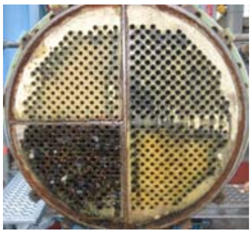
An Ecolab Company

Taking Energy Further™ 4

Mechanical stress parameters

Low velocity



Operational parameters	Low	Moderate	High	Severe
Skin Temperature (°C)	< 50	50 – 60	60 – 70	> 70
Velocity (ms^{-1})	> 1	0.6 – 1.0	0.6 – 0.3	< 0.3
Heat Flux ($MJm^{-2}.hr^{-1}$)	< 25	25 - 50	50 - 75	> 75
Chemical parameters				
Langelier	< 0.5	0.5 – 1.5	1.5 – 2.5	> 2.5
Ryznar	> 6.0	4.5 – 6.0	3.5 – 4.5	< 3.5
TCP SSI	< 20	20 –1000	1000 – 1500	>1500
Iron (mgl^{-1})	< 1.0	1.0 – 3.0	3.0 – 5.0	> 5.0

Increase corrosion and scaling risk

Stress...The New Normal

SYSTEM STRESS

Aging Systems	Hotter/Less Water
Increased Production	Higher Demand
Longer Runs	Better Results
Water Scarcity	Higher Cycles
Water Scarcity	Desalinated Make-up

RESULTS

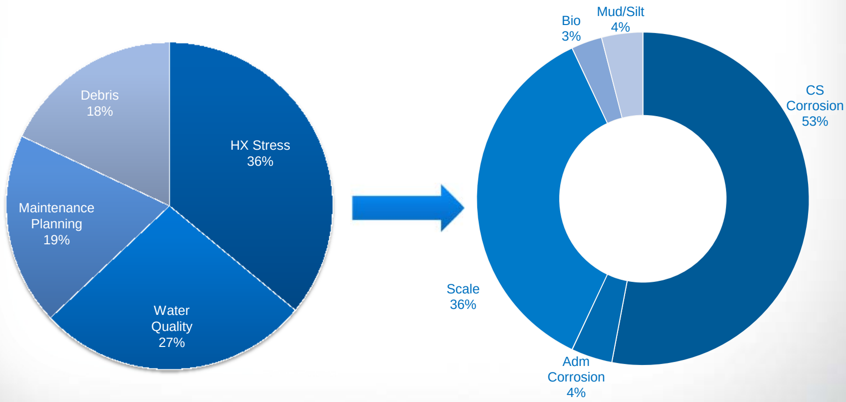
Optimum Reliability

Stress...The New Normal

Nalco Champion Innovation

Chemistry **Control** **Services**

System Reliability - Breakdown



Innovation request to R&D

- Superior PO_4 dispersancy
- Excellent Fe/Al tolerance
- Improved stability & MSDS
- 3D TRASAR tag control

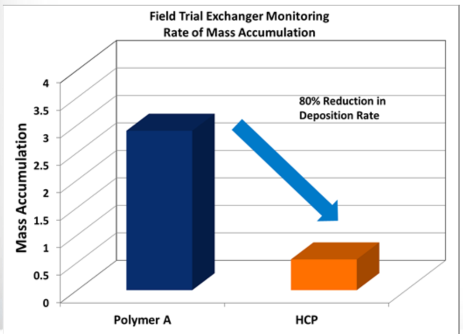
BENEFITS:

- Higher pH and cycles
- Reduced water use
- Enhanced stress management

NALCO Champion
An Ecolab Company

High Charge Polymer (HCP)

Polymer effectiveness determines the ability to operate at higher stress and cycle conditions. Research has determined that polymer efficiency is directly related to its charge. We have developed a polymer that balances the charge and molecular weight to maximize dispersant performance



- Superior PO_4 dispersancy
- Enhanced stress management
- Higher Fe & Al tolerance
- Higher pH and cycles
- Reduced water use
- Lower consumption
- Improved SDS

- CH-1918

NALCO Champion
An Ecolab Company

Technical Innovation → Improved Reliability → Customer Profits

HCP interaction with corrosion

- Superior iron dispersency, limits deposition
- Enhanced availability of corrosion inhibitors by best in class Zinc & phosphate stabilisation
- Tag polymer control to ensure inhibitor availability, as the dosing respond to system stress

3D TRASAR™
DETECT DETERMINE DELIVER

- Allows higher pH set point, reducing corrosion

New HCP

	OLD HSP TECHNOLOGY	HCP
Methanol in SDS?	YES	NO
Formaldehyde in SDS?	YES	NO
Formulation challenges?	YES	NO
Acrylamide monomer?	YES	NO
Chlorine consumption	YES*	NO
Fe and $CaHPO_4$ dispersion	Average	Excellent (HCP)

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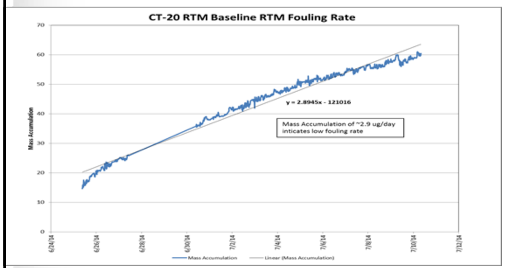
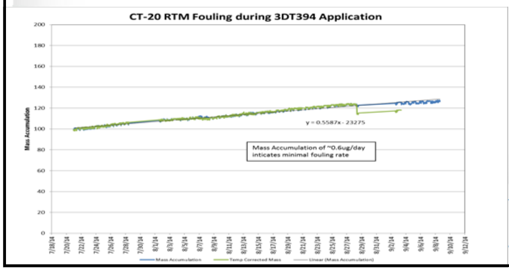
Case History #1

Deposition Rate from 2.9 ug/day to 0.6 ug/day





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High Charge Polymer Case History #1: Delivering water and TCO savings

- Reduced Deposition Rate by 80%(2.9 to 0.6 ug/day)
- Maintained corrosion rates at higher cycles. Lowered iron levels (0.41 to 0.15 ppm).
- Increased cycles of concentration (3.9 to 6.1)
- Reduce Polymer Consumption 20%
- Improved PO_4 solubility from 93% to near 100% (evidence of old deposit cleanup)
- Improved Zn solubility from 40% to near 100% (evidence of old deposit cleanup)

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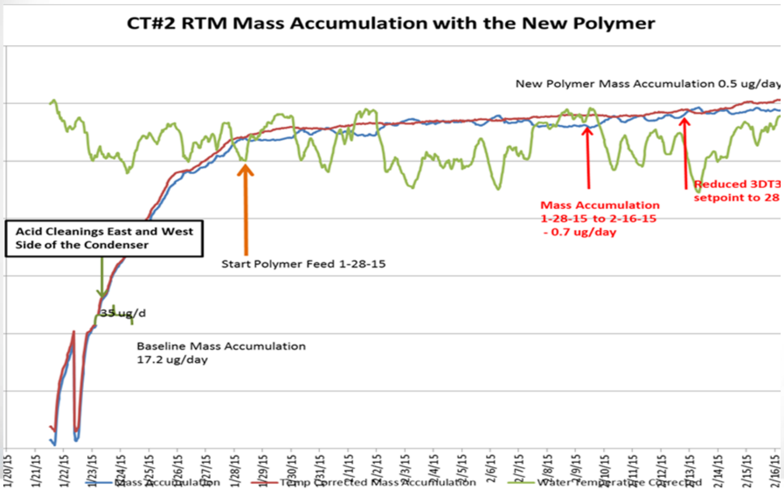
Case #2: HX with limited run-length, required periodic acid cleaning ($10m lost in downtime)

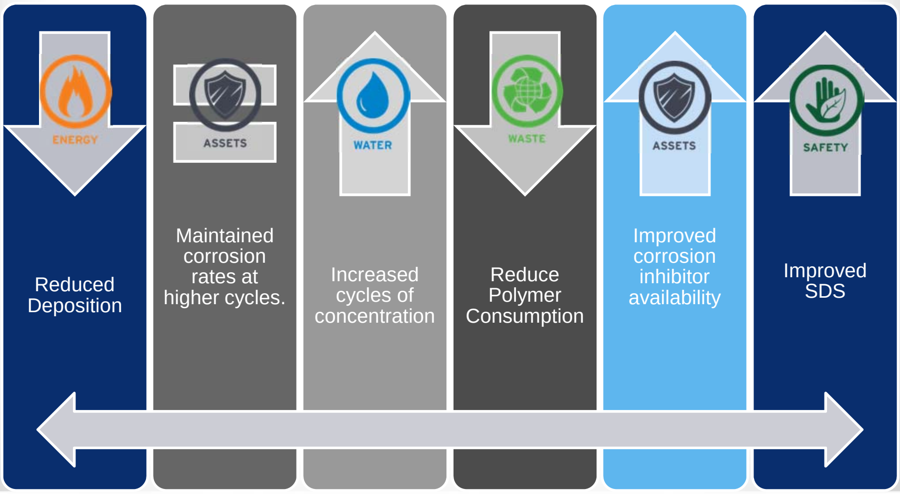
Pre-Trial Baseline
46 days exposure
RTM: 104 µg/d

HCP Trial
33 Days exposure
RTM: 10.5 µg/d

Case Study #3 – Refinery, variable MU, high Aluminium, periodic acid cleaning



High Charge Polymer Summary



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Questions?

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Appendix 9

Discussion about corrosion in cooling water systems as a result of poor water treatment

(G. De Lantsheer)

Cooling water treatment

Different treatment philosophies between different contractor can cause major defects

Gino De Landtsheer,
Senior Group Expert Piping & Valves
Borealis

Project & Technical Support (PTS)
Division: Technical Support Group (TS)

BOREALIS
Keep Discovering

Part 1:
Situation sketch

Situation sketch

⇨ It has been noted that changing contracts between CW treatment companies can have important impacts to:

a) Use of treatment philosophy , regarding the use of using additives

- Complete different chemical mix is even discovered
- Other dosing scenario's have been monitored

b) There are different ways of getting to the same result

- But how to get the warranties that the proposed solution will not affect our plants/equipment in a negative way?
- It has been even noted that between different locations with almost the same scope, a complete different treatment philosophies are discovered

c) What about the responsibilities in case it goes wrong?

- Short notice damages are quite easy, but what about the long term influences in relation to the scheduled/calculated equipment design life time.

d) Are there knowledge sharing platform available ?

- Libraries with analogue treatment scenario's could help the plant owner to evaluate proposals in water treatment scenario's

Part 2:
Some pictures what can go wrong…..

Cooling water treatment - issues

Cooling water treatment - issues

Cooling water treatment - issues

Thank you

Appendix 10

Denveloping guidelines and initiatives towards an holistic kind of approach to the CUI problem

(M. Mannucci and T. Rehberg)

FESI Presentation

Overview on some existing guidelines on protective coatings to prevent CUI
NACE SP0198– CINI Manual – AGI Q151 – API 583 – New ISO NP 19277

www.fesi.eu

WHAT IS AND WHAT DOES FESI

- FESI (Fédération Européenne des Syndicats d'Entreprises d'Isolation) is the independent Federation of the European insulation contracting sector founded in Paris in 1970.
- FESI represents 20 national insulation associations from Europe whose members are active in the field of technical insulation for industry, the commercial building sector, ship insulation, soundproofing and fire protection.
- FESI represents more than 3.300 European insulation contracting companies.

WHAT IS AND WHAT DOES FESI

FESI acts as the European think-tank bringing insulation specialists together to work on technical matters related to thermal and cold insulation as well as acoustic protection and to promote industrial insulation as a Best Available Technique delivering industry:

- ✓ Energy savings
- ✓ Emissions reductions
- ✓ System efficiency
- ✓ Safety
- ✓ Workplace improvement
- ✓ Cost reductions

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FESI'S THERMAL TECHNICAL COMMISSION

The Thermal Technical Commission (TTC) develops FESI's Thermal Technical Documents. It is responsible for standardization policy, information exchange with CEN, discussion of prENs with consequence for the insulation trade in Europe and recommendation of letters with a technical orientation to be written by FESI member associations to their respective representatives in the Standing Committee on Construction (SCC).

FESI’S TTC PROJECT ON CUI

Our aim is to achieve an updated view on best practices to minimize CUI, taking in consideration the following aspects:

- **Insulation materials selection and insulation installation techniques**
- **Coating system selection and their application techniques**
- **Mechanical Design**
- **Maintenance**
- **Inspections**

CUI – existing guidelines

- **NACE SP0198**, standard practice (first edition from 1998), “The Control of Corrosion Under Thermal Insulation and Fireproofing Materials — A Systems Approach”, current version from 2010, under revision since 2014
  coating system selection table and some design recommendations to avoid moisture intrusion

- **EFC Guideline No. 55** “Corrosion Under Insulation (CUI)” by Stefan Winnik, 2015
  same coating selection table as NACE SP0198 recommended practices to mitigate CUI with focus on RBI, TSA and coatings application and types and forms of insulation materials

- **AGI Q151** “Corrosion protection under insulation” first version from 1991, current version from 2013,
  coating system selection table

CUI – existing guidelines

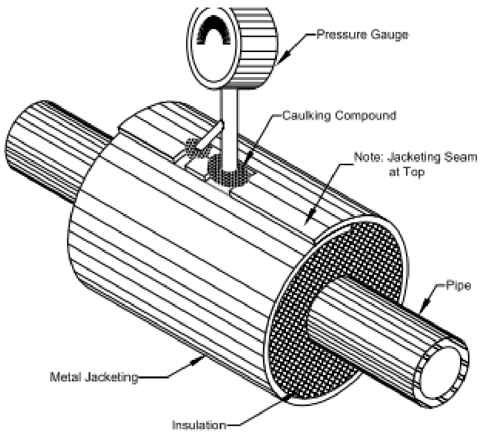
- **CINI** general insulation specification, chapter 1.2.04 and following currently under revision, "Relation between process temperature and possible corrosion under insulation", gives <u>recommended combination of systems and coatings to prevent CUI coating system selection table</u>

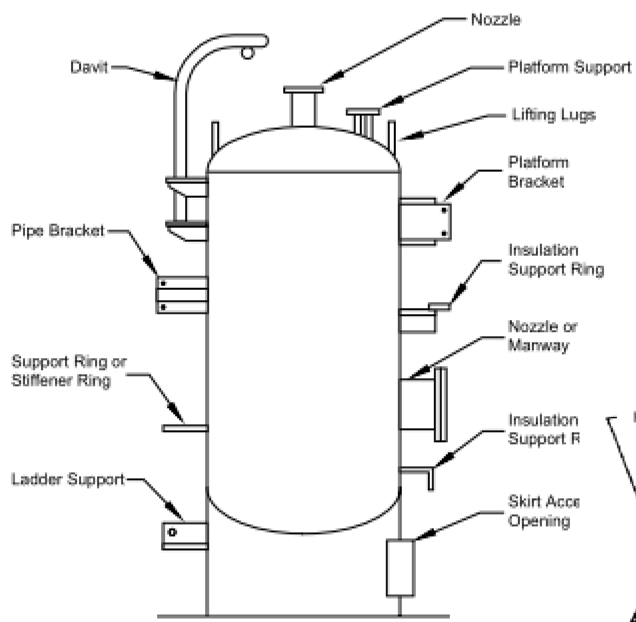
- **API 583,** 2014, gives design, maintenance, inspection and mitigstion practices to address corrosion under insulation

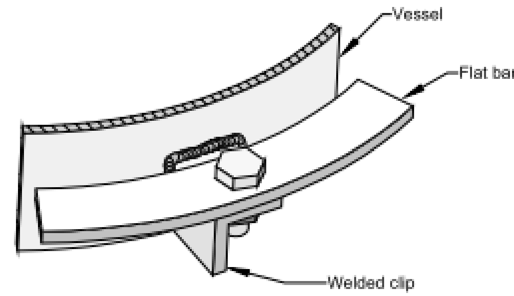
- **ISO NP 19288** – CUI coating laboratory testing regime

All before mentioned publications do not offer a full hollistic approach

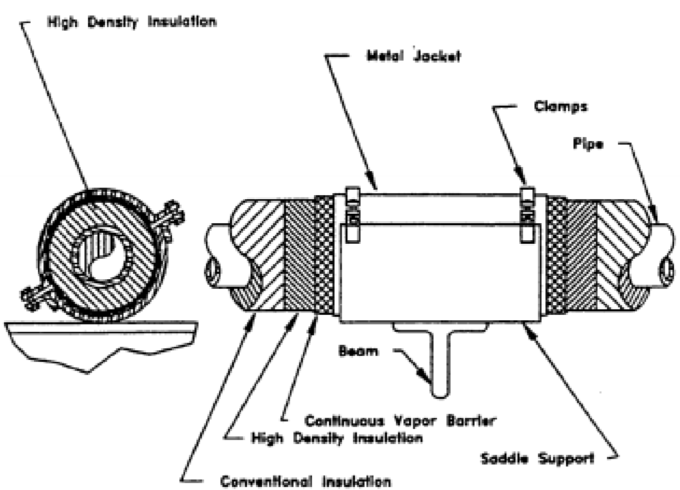
NACE SP0198: Insulation design considerations







Examples of design guidelines for insulation system engineering



NACE SP0198: Carbon Steel, corrosion protection

Table 1
Typical Protective Coating Systems for Austenitic and Duplex Stainless Steels Under Thermal Insulation

System Number	Temperature Range (A) (B)	Surface Preparation (C)	Surface Profile, µm (mil) (D)	Prime Coat, µm (mil) (E)	Finish Coat, µm (mil) (E)
SS-1	–45 to 60 °C (–50 to 140 °F)	SSPC-SP 1[11] and abrasive blast	50–75 (2–3)	High-build epoxy, 125–175 (5–7)	N/A
SS-2	–45 to 150 °C (–50 to 300 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
SS-3	–45 to 205 °C (–50 to 400 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy novolac, 100–200 (4–8)	Epoxy novolac, 100–200 (4–8)
SS-4	–45 to 540 °C (–50 to 1,000 °F)	SSPC-SP 1 and abrasive blast	15–25 (0.5–1.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)
SS-5	–45 to 650 °C (–50 to 1,200 °F)	SSPC-SP 1 and abrasive blast	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix,(F) 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix,(F) 100–150 (4–6)
SS-6	–45 to 595 °C (–50 to 1,100 °F)	SSPC-SP 1 and abrasive blast	50–100 (2–4)	Thermal-sprayed aluminum (TSA) with minimum of 99% aluminum, 250–375 (10–15)	Optional: sealer with either thinned epoxy-based or silicone coating (depending on max. service temperature) at approximately 40 (1.5)
SS-7	–45 to 540 °C (–50 to 1,000 °F)	SSPC-SP 1	N/A	Aluminum foil wrap with min. thickness of 64 (2.5)	N/A

NACE SP0198: Carbon Steel, corrosion protection

Table 2
Typical Protective Coating Systems for Carbon Steels Under Thermal Insulation and Fireproofing

System Number	Temperature Range [A] [B]	Surface Preparation	Surface Profile, µm (mil) [C]	Prime Coat, µm (mil) [D]	Finish Coat, µm (mil) [D]
CS-1	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10[14]	50–75 (2–3)	High-build epoxy, 130 (5)	Epoxy, 130 (5)
CS-2 (shop application only)	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	N/A	Fusion-bonded epoxy (FBE), 300 (12)
CS-3	–45 to 150 °C (–50 to 300 °F)	NACE No. 2/ SSPC- SP 10	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
CS-4	–45 to 205 °C (–50 to 400 °F)	NACE No. 2/ SSPC- SP 10	50–75 (2–3)	Epoxy novolac or silicone hybrid, 100–200 (4–8)	Epoxy novolac or silicone hybrid, 100–200 (4–8)
CS-5	–45 to 595 °C (–50 to 1,100 °F)	NACE No. 1/ SSPC-SP 5[15]	50–100 (2–4)	TSA, 250–375 (10–15) with minimum of 99% aluminum	Optional: Sealer with either a thinned epoxy-based or silicone coating (depending on maximum service temperature) at approximately 40 (1.5) thickness.
CS-6	–45 to 650 °C (–50 to 1,200 °F)	NACE No. 2/ SSPC-SP 10	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)
CS-7	60 °C (140 °F) maximum	SSPC-SP 2[16] or SSPC-SP 3[17]	N/A	Thin film of petrolatum or petroleum wax primer	Petrolatum or petroleum wax tape, 1–2 (40–80)
CS-8 Bulk or shop-primed pipe, coated with inorganic zinc	–45 to 400 °C (–50 to 750 °F)	Low-pressure water cleaning to 3,000 psi (20 MPa) if necessary	N/A	N/A	Epoxy novolac, epoxy phenolic, silicone, modified silicone, inorganic copolymer, or a coating with an inert multipolymeric matrix, is typically applied in the field. Consult coating manufacturer for thickness and service temperature limits. [E]

EFC 55 CUI guidelines

Table D.1 Typical protective coating systems for austenitic and duplex stainless steels under thermal insulation

System number	Temperature range[a,b]	Surface preparation[c]	Surface profile, µm (mil)[d]	Prime coat, µm (mil)[e]	Finish Coat, µm (mil)[e]
SS-1	−45 to 60 °C (−50 to 140 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	High-build epoxy, 125–175 (5–7)	N/A
SS-2	−45 to 150 °C (−50 to 300 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
SS-3	−45 to 205 °C (−50 to 400 °F)	SSPC-SP 1 and abrasive blast	50–75 (2–3)	Epoxy novolac, 100–200 (4–8)	Epoxy novolac, 100–200 (4–8)
SS-4	−45 to 540 °C (−50 to 1000 °F)	SSPC-SP 1 and abrasive blast	15–25 (0.5–1.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)	Air-dried silicone or modified silicone, 37–50 (1.5–2.0)
SS-5	−45 to 650 °C (−50 to ~1200 °F)	SSPC-SP 1 and abrasive blast	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix,[f] 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix,[f] 100–150 (4–6)
SS-6	−45 to 595 °C (−50 to 1100 °F)	SSPC-SP 1 and abrasive blast			

[a] The temperature range shown for a coating system is that range over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of austenitic and duplex stainless steels at certain temperatures. Temperature ranges are typical for the coating system; however, specifications and coating manufacturer's recommendations should be followed. SS-4, SS-5, SS-6, and SS-7 may be used under frequent thermal cyclic conditions in accordance with manufacturer's recommendations.

[b] Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures. An experienced metallurgist should be consulted before exposing duplex stainless steel to temperatures greater than 300 °C (572 °F).

[c] To avoid surface contamination, austenitic and duplex stainless steels shall be blasted with nonmetallic grit such as silicon carbide, garnet, or virgin aluminum oxide. Because there are no specifications for the degree of cleanliness of abrasive blasted austenitic and duplex stainless steels, the owner should state the degree of cleanliness required after abrasive blasting, if applicable, and whether existing coatings are to be totally removed or whether tightly adhering coatings are acceptable.

[d] Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. Coating manufacturer's recommendations should be followed.

[e] Coating thicknesses are typical dry film thickness (DFT) values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

[f] Consult with the coating manufacturer for actual temperature limits of these coatings.

EFC 55 CUI guidelines

Table D.2 Combined protective coating systems for carbon steels under thermal insulation

System number	Temperature range[a,b]	Surface preparation	Surface profile (µm)[c]	Prime coat (µm)[d]	Finish coat (µm)[d]
C-S-1	−45 to 60 °C	ISO SA-2.5	50–75	High-build epoxy, 130	Epoxy, 130
C/S-2 (shop application only)	−45 to 60 °C	ISO SA-2.5	50–75	N/A	Fusion-bonded epoxy (FBE), 300
C/S-3	−45 to 150 °C	ISO SA-2.5	50–75	Epoxy phenolic, 100–150	Epoxy phenolic, 100–150
C/S-4	−45 to 20 °C	ISO SA-2.5	50–75	Epoxy novolac or silicone hybrid, 100–200	Epoxy novolac or silicone hybrid, 100–200
C/S-5	−45 to 595 °C	IISO SA-3	50–100	TSA, 250–375 with minimum of 99% aluminum	Optional: Sealer with either a thinned epoxy or silicone coating (depending on service temperature) at approximately 40 thickness
C/S-6	−45 to 650 °C	ISO SA-2.5	40–65	Inorganic copolymer or coatings with an inert multipolymeric matrix,100–150	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150
S-7	−45 to 540 °C	N/A	N/A	Aluminum foil wrap with min. thickness of 64 (2.5)	N/A
C-8[e] Bulk or shop-primed pipe, coated with inorganic zinc	−45 to 400 °C	Low-pressure water cleaning to 20 MPa if necessary	N/A	N/A	Epoxy novolac, epoxy phenolic, silicone, modified silicone, inorganic copolymer, or a coating with an inert multipolymeric matrix is typically applied in the field. Consult coating specialist, manufacturer for thickness and service temperature limits[f]

EFC 55 CUI guidelines

Table 4.4 CUI susceptibility assessment for carbon and low alloy steels

Susceptibility factor			Susceptibility class N (score = 0)	L (score = 1)	M (score = 3)	H (score = 5)
Coating	No coating		–	<2 years	2–5 years	>5 years
Coating	Organic coating	Poor-quality coating or hand surface preparation	–	<8 years	–	>8 years
Coating	Organic coating	High-quality coating (immersion service) with good surface preparation	–	<12 years	Damaged coating <12 years	>12 years
Coating	Thermal sprayed aluminum (TSA)	Surface preparation with no QA/QC	<12 years	–	–	>12 years
Coating	Thermal sprayed aluminum (TSA)	Surface preparation with detailed QA/QC	<20 years	20–25 years	25–30 years	>30 years
Heat tracing			Not present	Present	–	–
Cladding/insulation condition			Good engineering standards Recently installed <5 years Preventative maintenance program	Good engineering standards 5–10 years Preventative maintenance program	Poor engineering standards 5–10 years Corrective maintenance	Poor engineering standards >10 years and/or system is visually in a bad state No maintenance
Local environment			Dry/indoors	Inland or mild industrial climate Rarely wetted: <10% of the time	Moderate coastal or industrial climate Frequently wetted: 30% of the time; rain or high humidity	Severe coastal or offshore climate Almost permanently wetted (e.g., cooling tower vicinity condensation, dripping)

EFC 55 CUI guidelines

Table 4.6 CUI susceptibility assessment for austenitic stainless steels

Susceptibility factor		Susceptibility class: N (score = 0)	L (score = 1)	M (score = 3)	H (score = 5)	E (score = 13)
Coating	Organic coating	–	–	<5 years		>5 years or damaged or porous coating
Coating	Thermal sprayed aluminum (TSA)	<10 years	10–20 years	20–30 years		>30 years
Aluminum foil (austenitic stainless steel only)		<8 years		8–10 years		>10 years
Cladding/insulation condition		Good engineering standards Recently installed <5 years Preventative maintenance program	Good engineering standards 5–10 years Preventative maintenance program	Poor engineering standards 5–10 years Corrective maintenance program	Poor engineering standards >10 years and/or system is visually in a bad state Corrective maintenance program	
Local environment		Dry/indoors	Inland or mild industrial climate: Rarely wetted <10% of the time	Moderate coastal or industrial climate: Frequently wetted 30% of the time; rain or high humidity	Severe coastal or offshore climate: Almost permanently wetted	

AGI Q 151 – Corrosion protection under insulation

- Gives generic system selection for carbon and stainless steel
- All systems (except the touch-up/repair system) require Sa 2½
- For cyclic condition special solutions are suggested

No surface protection system is required:

- Continuously operating equipment & piping below -20°C
- Insulated surfaces operating above 120°C
- Stainless steel surfaces which are continuously operated below +20°C and will no reach more than +35°C during shut down and which are not cleaned with warm media

Tabelle 1 / Table 1

Beschichtungssysteme für unlegierte/ niedrig legierte Stähle / Paint-systems for carbon and low-alloy steels							
Betriebstemperatur [*T*] Operating Temperature	Beschichtungs-System Nr. Paint System No.	Oberflächen-vorbereitung, gemäß DIN EN ISO 12944-4/ SSPC Surface preparation acc. to DIN EN ISO 12944-4/ SSPC	Grundbeschichtung Prime coat		Deckbeschichtung Top coat		Gesamtsystem Complete system
			Typ Type	Sollschichtdicke Nominal dry film thickness (NDFT)	Typ Type	Sollschichtdicke Nominal dry film thickness (NDFT)	Sollschichtdicke Total nominal dry film thickness (NDFT)
-20 °C ≤ *T* ≤ +150 °C	1.1	Sa 2 ½[1]) SSPC-SP10[1])	EP-Zn(R) Epoxy-Zn(R)	80 µm	EP-EG Epoxy-MIO	80 µm	160 µm
	1.2	Sa 2 ½[1]) SSPC-SP10[1])	PUR – Zn(R) PUR-Zn(R)	80 µm	PUR-EG PUR-MIO	80 µm	160 µm
	1.3	Sa 2 ½[1]) SSPC-SP10[1])	ESI	60 µm	EP-EG Epoxy-MIO	80 µm	140 µm
	1.4	Sa 2 ½[1]) SSPC-SP10[1])	EP	80 µm	EP	80 µm	160 µm
+ 150 °C ≤ *T* ≤ + 200 °C	1.5	Sa 2 ½[1]) SSPC-SP10[1])	ESI	60 µm	SI-AY	2 x 30 µm	120 µm
+ 200 °C ≤ *T* ≤ + 400 °C	1.6	Sa 2 ½[1]) SSPC-SP10[1])	ESI	60 µm	SI-AI	2 x 30 µm	120 µm
Reparatur-/Instandhaltungs-Beschichtung Maintenance-system -20 °C ≤ *T* ≤ + 150 °C	1.7	St3, PMa SSPC SP-3	EP (oberfl.-tolerant) EP surface-tolerant	80 µm	EP	80 µm	160 µm
Beschichtungssysteme für unlegierte/niedrig legierte Stähle, bei periodisch wechselnden Temperaturen und hochkorrosiver Atmosphäre Paint-systems for carbon-steel at periodic changing temperatures and high corrosive atmosphere							
-20 °C ≤ *T* ≤ + 200 °C	1.8	Sa 2 ½[1]) SSPC-SP10[1])	EP Phenolharz EP phenolic	100 µm	EP/ Phenolharz EP/phenolic	100 µm	200 µm
-20 °C ≤ *T* ≤ + 600 °C	1.9	Sa 2 ½[1]) SSPC-SP10[1])	CSA	150 µm	SI-AI	50 µm	200 µm

Tabelle 2 / Table 2

Beschichtungssysteme für nichtrostende austenitische Stähle / Paint systems for austenitic stainless steel							
-20 °C ≤ *T* ≤ + 150 °C	2.1	Sweep-Strahlen sweep-blasting	EP	80 µm	EP	80 µm	160 µm
	2.2	Sweep-Strahlen sweep-blasting	PUR	80 µm	PUR	80 µm	160 µm
+ 150 °C ≤ *T* ≤ + 200 °C	2.3	Sweep-Strahlen sweep-blasting	SI-AY	30 µm	SI-AY	30 µm	60 µm
+ 200 °C ≤ *T* ≤ + 400 °C	2.4	Sweep-Strahlen sweep-blasting	SI-AI	30 µm	SI-AI	30 µm	60 µm

AGI Q151

¹) Anmerkung / Note: Kann nicht gestrahlt werden, so sind andere Beschichtungssysteme einzusetzen. Der Korrosionsschutz ist reduziert!
If blasting is not possible, other paint-systems shall be used. The corrosion protection is reduced!

CSA: Cold Sprayed Aluminium; Titanmodifiziertes anorganisches Copolymer mit metallischem Aluminium pigmentiert / titanium modified inorganic copolymer, pigmented with metallic aluminium
EP: Epoxid Bindemittel / Epoxy Binder
ESI: Ethylsilikat mit Zinkstaub / Inorganic zinc-silicate
PUR: Polyurethan-Bindemittel / Polyurethane Binder
SI-AY: Silikon-Acryl-Bindemittel / Silicone-Acrylic binder
SI-Al: Silikon Bindemittel mit Aluminiumpigmentierung / Silicone Binder, aluminium pigmented
(Zn): Zinkstaub (Zinkanteil > 80%) / Zinc-rich (content > 80%)
(EG): Eisenglimmer pigmentiert / Micaceous iron oxide (MIO) pigmented
SSPC: Steel Structure Painting Council

Tabelle 3 / Table 3

Beschichtungssysteme für unlegierte/niedrig legierte Stähle in hochkorrosiver Atmosphäre, z.B. Offshore / Paint-systems for carbon-steel in high corrosive atmosphere, e.g. offshore							
Betriebstemperatur [7] Operating temperature	Beschichtungs-System Nr. Paint-system No.	Oberflächen-vorbereitung, gemäß DIN EN ISO 12944-4/ SSPC Surface preparation acc. to DIN EN ISO 12944-4/ SSPC	Grundbeschichtung Prime coat		Deckbeschichtung Sealer coat		Gesamtsystem Complete system
			Typ Type	Sollschichtdicke Nominal dry film thickness (NDFT)	Typ Type	Sollschichtdicke Nominal dry film thickness (NDFT)	Sollschichtdicke Total nominal dry film thickness (NDFT)
-20 °C ≤ T ≤ + 150 °C	3.1	Sa 3 SSPC SP5	TSA	200 µm	EP	60 µm	260 µm
+150 °C ≤ T ≤ + 200 °C	3.2	Sa 3 SSPC SP5	TSA	200 µm	SI-AY	2 x 30 µm	260 µm
+ 200 °C ≤ T ≤ + 600 °C	3.3	Sa 3 SSPC 5	TSA	200 µm	SI-Al	2 x 30 µm	260 µm

API 583

For newly installed piping, CUI concerns are frequently addressed by the use of high-quality protective coatings or TSA. However, this solution can be expensive for use in remediation. This high cost of remediation has contributed to the current industry challenges associated with CUI. Therefore, one should consider initial long-term prevention options. This cost and value of an initial prevention option may be assessed using a life cycle analysis based on the remediation method selected. This analysis should consider the remediation costs, the future inspection costs, and the costs associated with loss of containment as the result of failure of the equipment pressure boundary, etc. The surface preparation for the application of most epoxy or metal filled paints can be extensive; some require grit blast to white metal. In some cases the best alternative for remediation is to replace the entire section with new pipe.

9.2.2 Carbon steel should be coated with one of the following coating types: epoxy amine, epoxy polyamide, or zinc phosphate phenolic, all of which may be used up to the maximum temperature limits recommended by the manufacturer of the particular product. It should be emphasized that the coating manufacturer's application instructions be strictly followed to optimize coating performance. This includes such conditions as relative humidity/ temperature limitations, standards of surface preparation, and the length of time between priming and topcoating to prevent intercoat adhesion difficulties. Within the past several years, numerous owner/users have specified the application of TSA to reduce the potential for corrosion in applications prone to CUI damage. As with any applied coating, surface preparation and application concerns need to be addressed to maximize the service life of the coating (see 11.5).

9.2.3 If special protection is required, the surface should be degreased and then coated. Water glass (sodium silicate) is used to coat the surface when inhibited calcium silicate is the specified insulation material. A silicone-acrylic coating (guaranteed free from low melting point metals, e.g. zinc) is used when foam glass, mineral wool, etc., are the specified insulations. For stainless steel equipment, some operators specify wrapping the equipment with aluminum foil prior to insulating for additional protection by acting as both a physical and a galvanic barrier to preventing ECSCC.

API 583

9.8.2 Coating Considerations

A coating system should protect against water or corrosives for long periods. Highly permeable organic coatings allow corrosion to start behind the coating even in the absence of breaks or pinholes. As a result, organic coating systems that are suitable for immersion service are usually preferred where there is a potential for CUI damage. Typically, a prime coat and topcoat are required to adequately protect a component from corrosion. Application of solely a primer will not provide adequate corrosion resistance.

Before a coating is applied to a component surfaces, the surface should be dry and clean from contaminants and rust. For CUI applications, a white-metal blast cleaning (SSPC SP-5 or equivalent) is preferred, though a “good” near-white-metal blast cleaning (SSPC-10 or equivalent) may be acceptable. The adequacy of the surface preparation can significantly impact the durability of the coating. For CUI applications, high-build epoxies or epoxy-phenolics are often specified at temperatures up to about 250 °F (120 °C). At higher temperatures, a high-temperature coating (e.g. a two-coat heat-resisting silicone coating) is required.

It should be noted that many coating systems fail after 10 years in service. After the coating breaks down, the bare steel can be attacked by CUI. By contrast, TSA coatings are generally reported to have a useful service lifetime in excess of 35 years though service life can be reduced because of improper coating application (see 11.5.4).

ISO NP 19277 - Qualification testing for protective coating systems under insulation

Table 1 — CUI classification environments

Classification	Minimum temperature	Peak temperature range
CUI-1	−45 °C	−45 °C to 60 °C
CUI-2	−45 °C	60 °C to 150 °C
CUI-3	−45 °C	150 °C to 204 °C
CUI-4	−45 °C	204 °C to 300 °C

For insulated service for temperatures above 300 °C additional testing can be performed as agreed to by interested parties.

Table 2 — CUI classification cryogenic environments

Classification	Minimum temperature	Peak temperature range
CUI-1-Cryo	−196 °C	−45 °C to 60 °C
CUI-2-Cryo	−196 °C	60 °C to 150 °C

ISO NP 19277 - Test regime CUI-1 – CUI-4

- Adhesion testing before conditioning (ISO 2409 or 4624)

Criteria: ISO 2409 0-2 and ISO 4624 cohesive failure, unless over 5MPa

- Neutral salt spray (ISO 9227) for 720/480 hours
- Immersion testing (ISO 2812-2) for 3000/500 hours
- Water condensation (ISO 6270-1) for 480/240 hours

Ambient test criteria “0” in ISO 4628-2, -3, -4, -5, -8

- Adhesion testing after conditioning (ISO 2409 or ISO 4624)

Criteria: ISO 2409 0-2 and ISO 4624 cohesive failure, unless over 5MPa

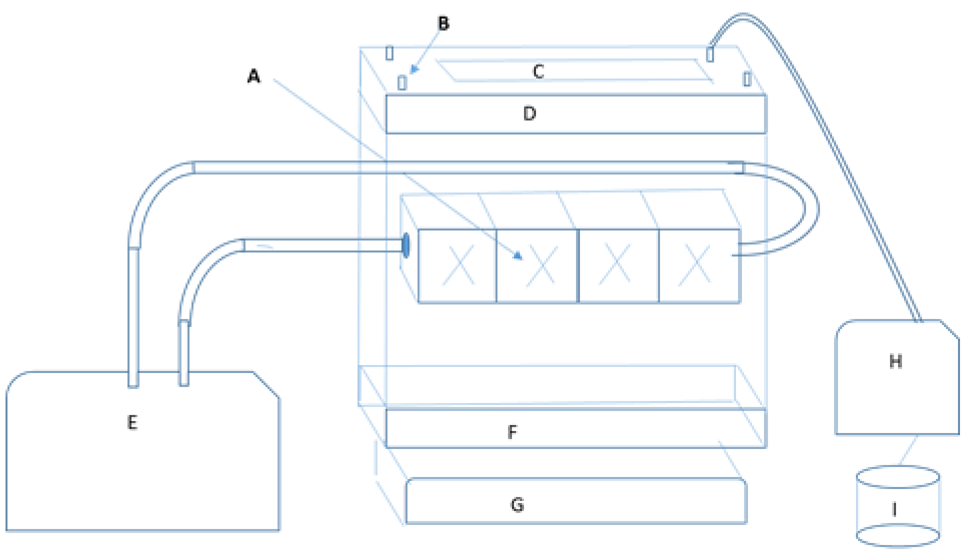
- Thermal cycling test (20 cycles (max. temp. and ice water))

Test criteria “0” in ISO 4628-2, -3, -4, -5

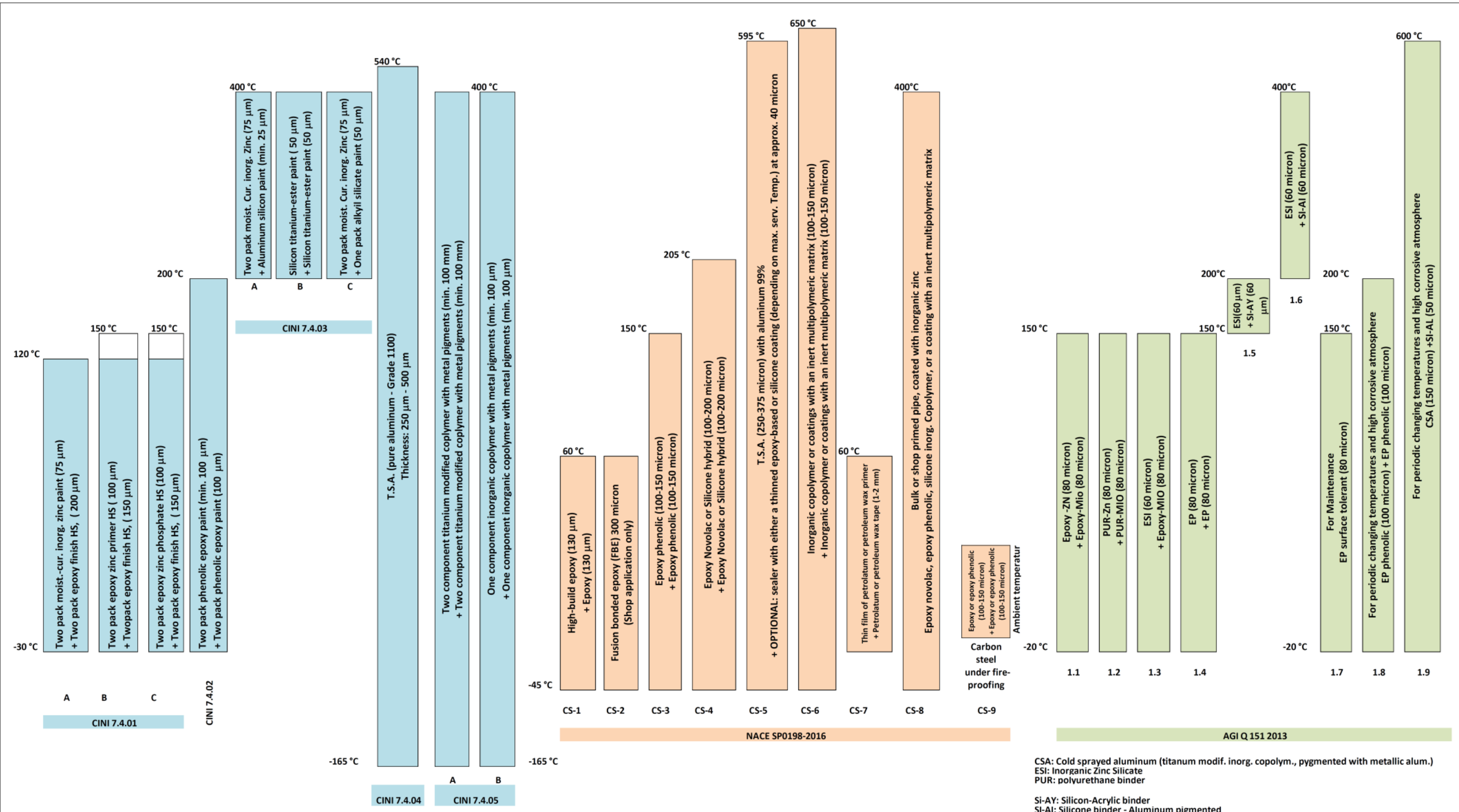
- Multi-phase CUI cyclic test (1008 hours CUI-2 – CUI-4)

Test criteria “0” in ISO 4628-2, -3, -4, -5, -8

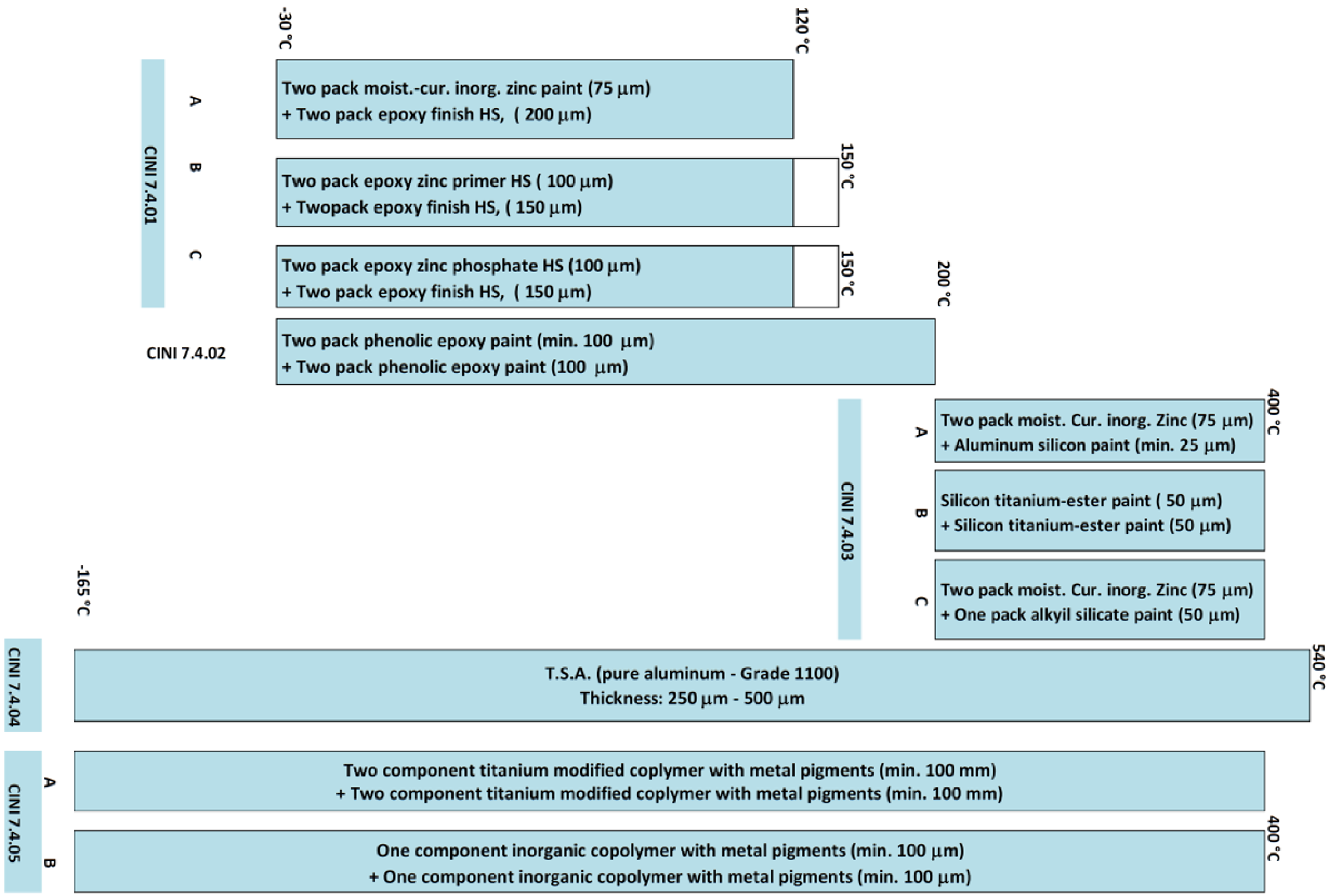
Multi Phase CUI test chamber

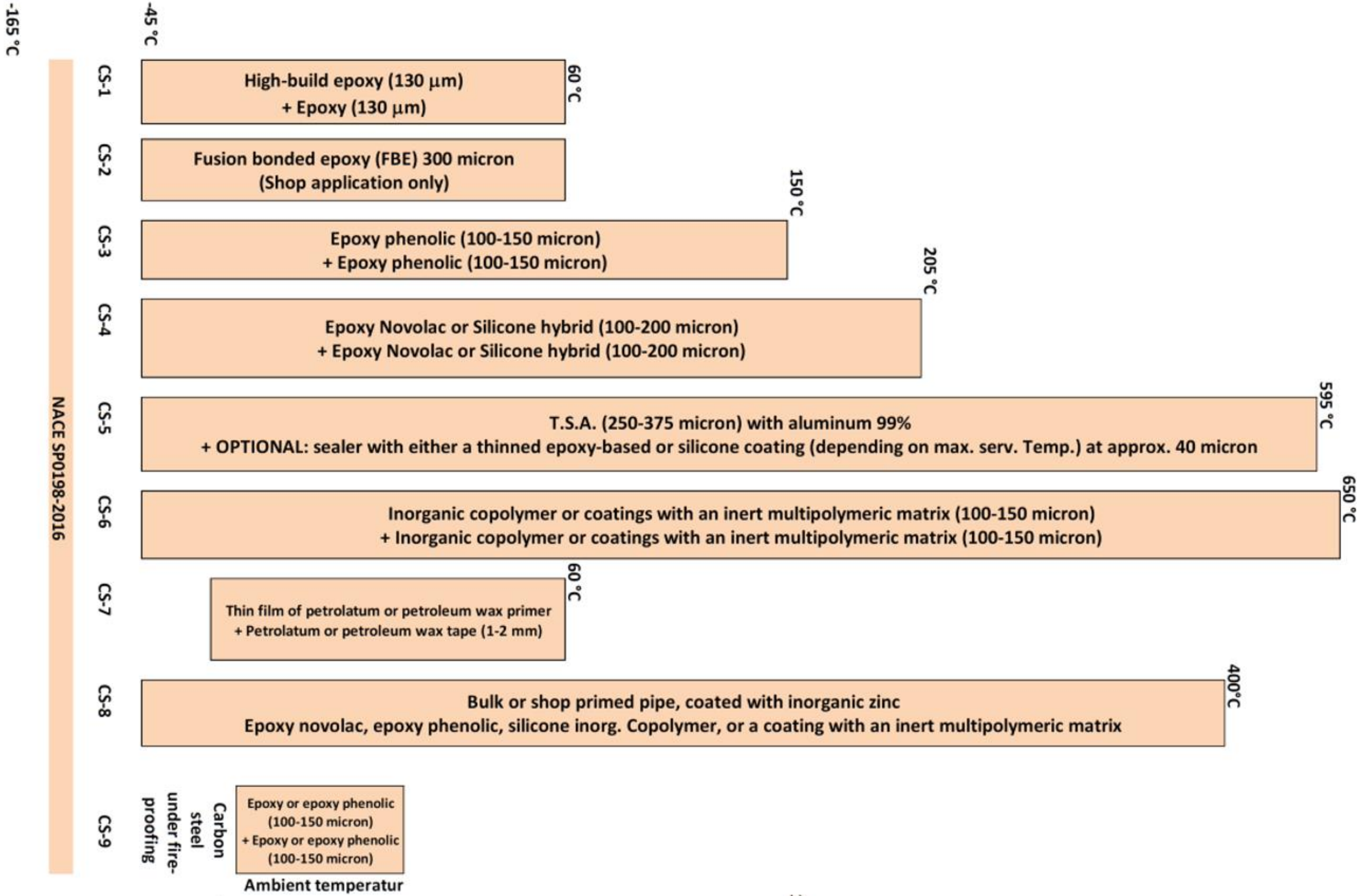


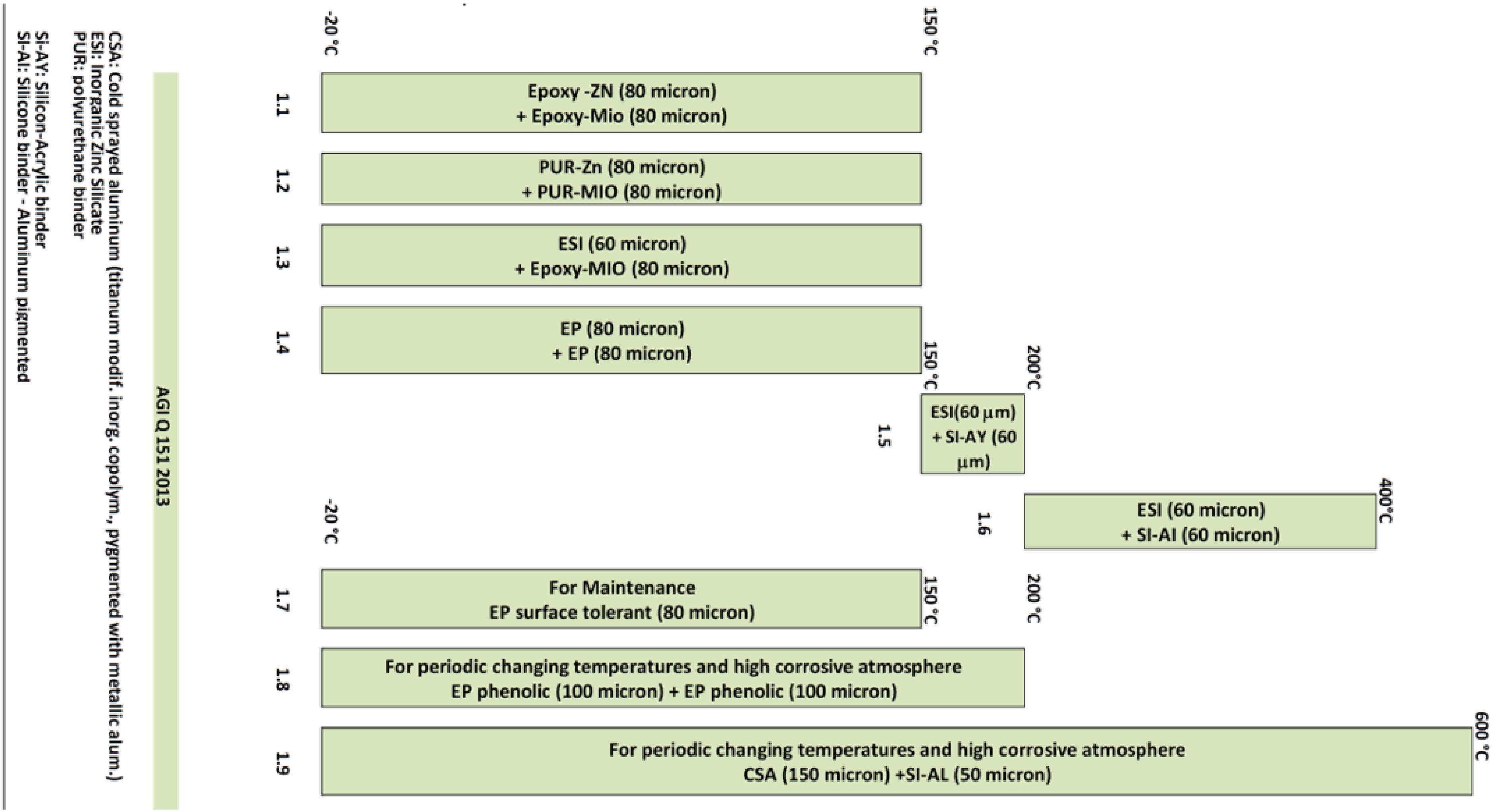
Multi Phase CUI Test Chamber – Open View



120 °C
-30 °C
Two pack moist.-cur. inorg. zinc paint (75 µm) + Two pack epoxy finish HS, (200 µm)
150 °C
Two pack epoxy zinc primer HS (100 µm) + Twopack epoxy finish HS, (150 µm)
150 °C
Two pack epoxy zinc phosphate HS (100 µm) + Two pack epoxy finish HS, (150 µm)
200 °C
Two pack phenolic epoxy paint (min. 100 µm) + Two pack phenolic epoxy paint (100 µm)
A
B
C
CINI 7.4.01
CINI 7.4.02
400 °C
Two pack moist. Cur. inorg. Zinc (75 µm) + Aluminum silicon paint (min. 25 µm)
Silicon titanium-ester paint (50 µm) + Silicon titanium-ester paint (50 µm)
Two pack moist. Cur. inorg. Zinc (75 µm) + One pack alkyl silicate paint (50 µm)
A
B
C
CINI 7.4.03
540 °C
T.S.A. (pure aluminum - Grade 1100) Thickness: 250 µm - 500 µm
-165 °C
CINI 7.4.04
400 °C
Two component titanium modified coplymer with metal pigments (min. 100 mm) + Two component titanium modified coplymer with metal pigments (min. 100 mm)
One component inorganic copolymer with metal pigments (min. 100 µm) + One component inorganic copolymer with metal pigments (min. 100 µm)
A
B
CINI 7.4.05
-165 °C
-45 °C
60 °C
High-build epoxy (130 µm) + Epoxy (130 µm)
Fusion bonded epoxy (FBE) 300 micron (Shop application only)
150 °C
Epoxy phenolic (100-150 micron) + Epoxy phenolic (100-150 micron)
205 °C
Epoxy Novolac or Silicone hybrid (100-200 micron) + Epoxy Novolac or Silicone hybrid (100-200 micron)
595 °C
T.S.A. (250-375 micron) with aluminum 99% + OPTIONAL: sealer with either a thinned epoxy-based or silicone coating (depending on max. serv. Temp.) at approx. 40 micron
650 °C
Inorganic copolymer or coatings with an inert multipolymeric matrix (100-150 micron) + Inorganic copolymer or coatings with an inert multipolymeric matrix (100-150 micron)
60 °C
Thin film of petrolatum or petroleum wax primer + Petrolatum or petroleum wax tape (1-2 mm)
400°C
Bulk or shop primed pipe, coated with inorganic zinc Epoxy novolac, epoxy phenolic, silicone inorg. Copolymer, or a coating with an inert multipolymeric matrix
Epoxy or epoxy phenolic (100-150 micron) + Epoxy or epoxy phenolic (100-150 micron)
Ambient temperatur
Carbon steel under fire-proofing
CS-1
CS-2
CS-3
CS-4
CS-5
CS-6
CS-7
CS-8
CS-9
NACE SP0198-2016
150 °C
-20 °C
Epoxy -ZN (80 micron) + Epoxy-Mio (80 micron)
PUR-Zn (80 micron) + PUR-MIO (80 micron)
ESI (60 micron) + Epoxy-MIO (80 micron)
EP (80 micron) + EP (80 micron)
150 °C
200°C
ESI(60 µm) + SI-AY (60 µm)
400°C
ESI (60 micron) + SI-Al (60 micron)
200 °C
150 °C
-20 °C
For Maintenance EP surface tolerant (80 micron)
For periodic changing temperatures and high corrosive atmosphere EP phenolic (100 micron) + EP phenolic (100 micron)
600 °C
For periodic changing temperatures and high corrosive atmosphere CSA (150 micron) +SI-AL (50 micron)
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
AGI Q 151 2013
CSA: Cold sprayed aluminum (titanum modif. inorg. copolym., pygmented with metallic alum.)
ESI: Inorganic Zinc Silicate
PUR: polyurethane binder
Si-AY: Silicon-Acrylic binder
SI-Al: Silicone binder - Aluminum pigmented


-30 °C
120 °C
CINI 7.4.01
A
Two pack moist.-cur. inorg. zinc paint (75 µm)
+ Two pack epoxy finish HS, (200 µm)
B
Two pack epoxy zinc primer HS (100 µm)
+ Twopack epoxy finish HS, (150 µm)
150 °C
C
Two pack epoxy zinc phosphate HS (100 µm)
+ Two pack epoxy finish HS, (150 µm)
150 °C
200 °C
CINI 7.4.02
Two pack phenolic epoxy paint (min. 100 µm)
+ Two pack phenolic epoxy paint (100 µm)
CINI 7.4.03
A
Two pack moist. Cur. inorg. Zinc (75 µm)
+ Aluminum silicon paint (min. 25 µm)
400 °C
B
Silicon titanium-ester paint (50 µm)
+ Silicon titanium-ester paint (50 µm)
C
Two pack moist. Cur. inorg. Zinc (75 µm)
+ One pack alkyil silicate paint (50 µm)
-165 °C
CINI 7.4.04
T.S.A. (pure aluminum - Grade 1100)
Thickness: 250 µm - 500 µm
540 °C
CINI 7.4.05
A
Two component titanium modified coplymer with metal pigments (min. 100 mm)
+ Two component titanium modified coplymer with metal pigments (min. 100 mm)
B
One component inorganic copolymer with metal pigments (min. 100 µm)
+ One component inorganic copolymer with metal pigments (min. 100 µm)
400 °C


-165 °C
-45 °C
NACE SP0198-2016
CS-1
High-build epoxy (130 µm)
+ Epoxy (130 µm)
60 °C
CS-2
Fusion bonded epoxy (FBE) 300 micron
(Shop application only)
150 °C
CS-3
Epoxy phenolic (100-150 micron)
+ Epoxy phenolic (100-150 micron)
205 °C
CS-4
Epoxy Novolac or Silicone hybrid (100-200 micron)
+ Epoxy Novolac or Silicone hybrid (100-200 micron)
595 °C
CS-5
T.S.A. (250-375 micron) with aluminum 99%
+ OPTIONAL: sealer with either a thinned epoxy-based or silicone coating (depending on max. serv. Temp.) at approx. 40 micron
650 °C
CS-6
Inorganic copolymer or coatings with an inert multipolymeric matrix (100-150 micron)
+ Inorganic copolymer or coatings with an inert multipolymeric matrix (100-150 micron)
60 °C
CS-7
Thin film of petrolatum or petroleum wax primer
+ Petrolatum or petroleum wax tape (1-2 mm)
400°C
CS-8
Bulk or shop primed pipe, coated with inorganic zinc
Epoxy novolac, epoxy phenolic, silicone inorg. Copolymer, or a coating with an inert multipolymeric matrix
CS-9
Carbon steel under fire-proofing
Epoxy or epoxy phenolic (100-150 micron)
+ Epoxy or epoxy phenolic (100-150 micron)
Ambient temperatur


AGI Q 151 2013
-20 °C
150 °C
1.1
Epoxy -ZN (80 micron)
+ Epoxy-Mio (80 micron)
1.2
PUR-Zn (80 micron)
+ PUR-MIO (80 micron)
1.3
ESI (60 micron)
+ Epoxy-MIO (80 micron)
1.4
EP (80 micron)
+ EP (80 micron)
150 °C
200°C
1.5
ESI(60 µm)
+ SI-AY (60 µm)
-20 °C
1.6
ESI (60 micron)
+ SI-Al (60 micron)
400°C
1.7
For Maintenance
EP surface tolerant (80 micron)
150 °C
200 °C
1.8
For periodic changing temperatures and high corrosive atmosphere
EP phenolic (100 micron) + EP phenolic (100 micron)
1.9
For periodic changing temperatures and high corrosive atmosphere
CSA (150 micron) +SI-AL (50 micron)
600 °C
CSA: Cold sprayed aluminum (titanum modif. inorg. copolym., pygmented with metallic alum.)
ESI: Inorganic Zinc Silicate
PUR: polyurethane binder
Si-AY: Silicon-Acrylic binder
SI-Al: Silicone binder - Aluminum pigmented

FESI Interactive Selection System (FISS) against CUI

PROPOSAL

Operating Conditions

- Steel alloy
- Temperature
- Environment
- Lifetime expectancy

Coating System

- New build or Rehab
- Lifetime expectancy

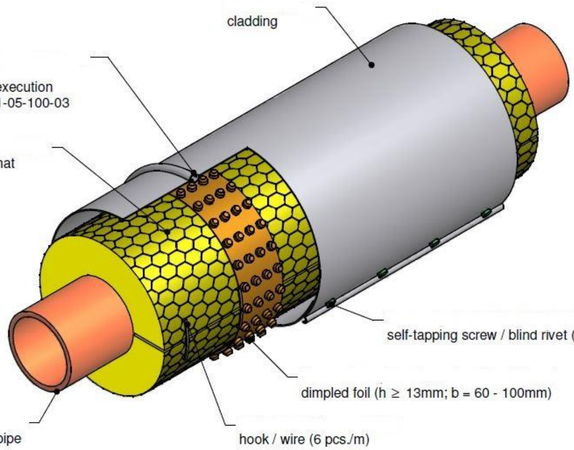
Insulation System

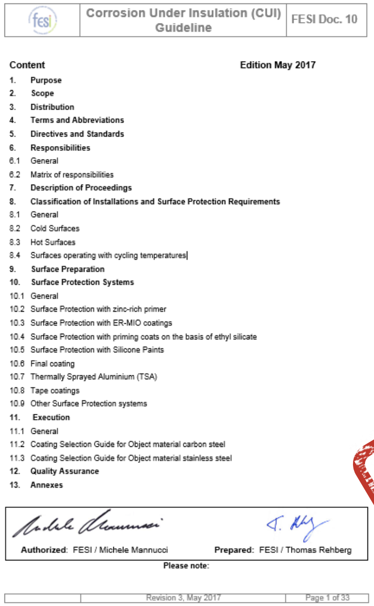
- Purpose of insulation (energy conservation, etc.)
- Lifetime expectancy

Effective CUI resistant insulation system

FESI Interactive Selection System (FISS) against CUI

- Holistic System approach, but real product combination (not generic)
- Considers the whole insulation system (from cladding to coating)
- Interactive combination of individual materials / material groups and best practices for individual selection and scoring (best possible system)





	Corrosion Under Insulation (CUI) Guideline	FESI Doc. 10

Content — **Edition May 2017**

Authorized: FESI / Michele Mannucci — **Prepared:** FESI / Thomas Rehberg

Please note:

	Revision 3, May 2017	Page 1 of 33

PROPOSAL

Roadmap to FESI Interactive Selection System (FISS)

- Workshop with coating manufacturer 2017, February 08 – 09
- Workshop with insulation manufacturer 2017, May 03 – 04
- Evaluation of EU funding possibilities – ongoing –
- Cooperation with NACE TG 516 on Laboratory test standard for CUI coatings
- Cooperation with CINI on FISS (FESI Interactive Selection System) – started

What we want from you

- Feedback on the initiative
- Ideas, Best Practises & Problems
- Participation in one of the next meetings with CINI
- Be available for FISS peer review

THANK YOU!

Appendix 11

Status of monitoring and detection procedures/techniques to detect CUI mitigating CUI, ones discovered, how to challenge, to challenge and to follow-up. Integration of mitigated CUI areas in RBI systems, how to re-evaluate?

(G. De Lantsheer)

Corrosion Under Insulation in process industry applications

Experience – awareness – controlling
⇨ key factors for a long-term approach

By means of knowledge, sharing of experiences and specific inspection programs, based on Risk Based Inspection principles, trying to break the circle of CUI.

Gino De Landtsheer,
Senior Group Expert Piping & Valves
Borealis

Project & Technical Support (PTS)
Division: Technical Support Group (TS)

Cornerstones

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Cornerstones

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Road map to manage CUI????

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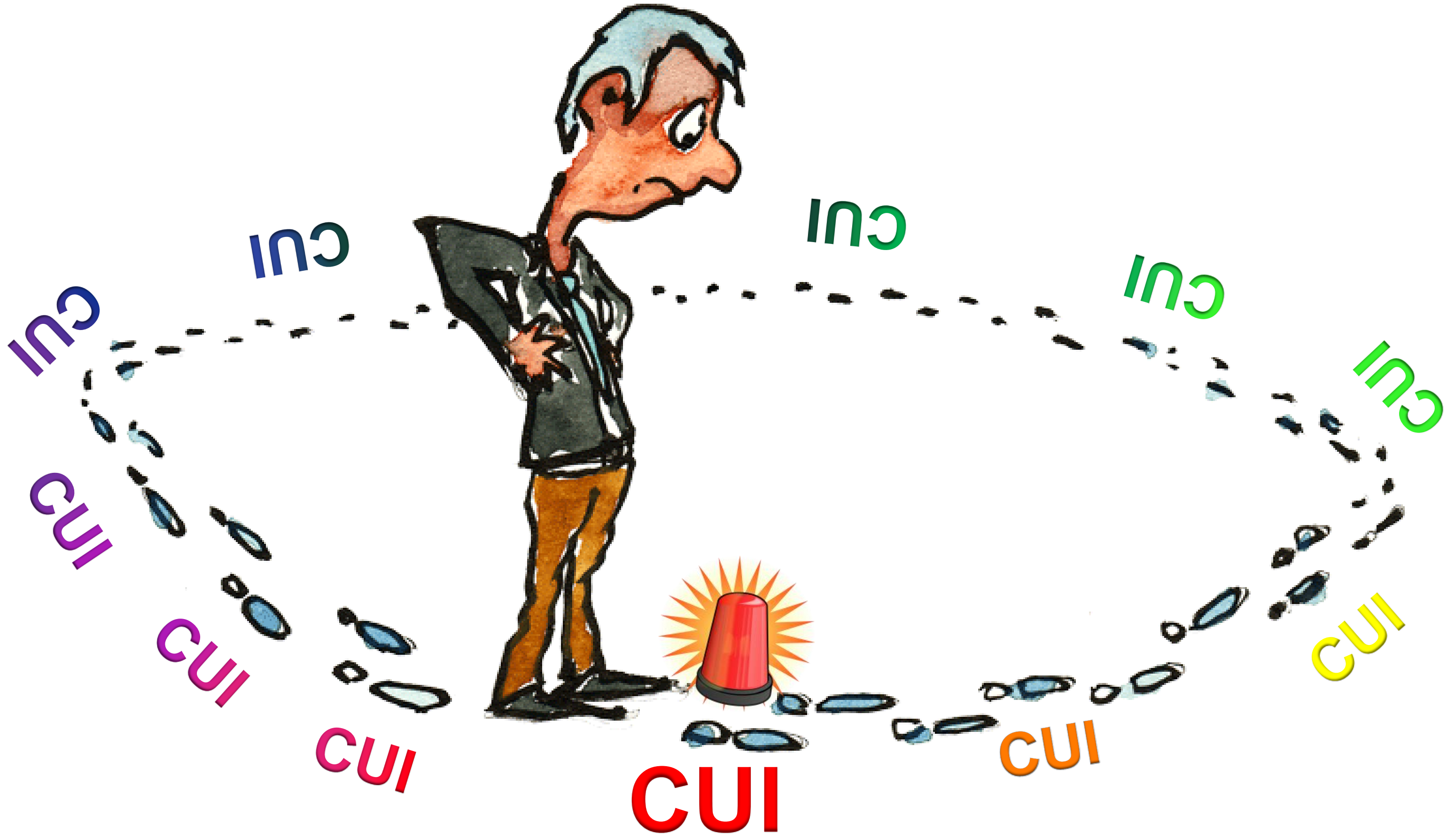
Road map to manage CUI

ROAD MAP ????



Points where we can make the difference!!!

Selection & application painting/coating systems

- A well–selected/well–applied painting/coating system must be seen as
  - Final layer of defence against corrosion
- It is wishfull thinking to assume that insulation systems will be waterproof (thight) during the expected lifetime.
- Coating & insulation systems shall be seen as equal partners in our continuous fight against CUI
- Is the applied coating method still the 'best in class' solution / and is aging monitored?
- Is the applied coating quality meeting our expectations?

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Knowledge – CUI: critical spots

Possible water intrusion in the applied insulation

- Low quality in the applied weather protecting sheeting of the insulation / openings due to damaging
- Leakage of installed steam tracing / cut-outs in the insulation where the steam tracing is entering the insulation
- Possible condensation by process conditions or damaged vapor screens
- Each cut-out in the weather protection sheeting (tie-ins / instrument take-offs/connecting points for hangers) is increasing the risk
- Supporting positions, flange locations, valves and end-points of insulation (vertical lines!)
- Valve & equipment boxes!
- Degenerated sealing materials (UV impact to silicone kit)

Resource of water / humidity

- Climate conditions (temperature / humidity / geographical (sea))
- Local conditions (firewater system tests / cooling towers / high pressure cleaning / water spils and leaks)
- CUI can be very aggresive at locations with frequent and wide band temperature fluctuations in process temperatures, resulting condensing and vaporasation effects (also known as swetting of piping)

Knowledge – CUI: critical spots

Design and concept related

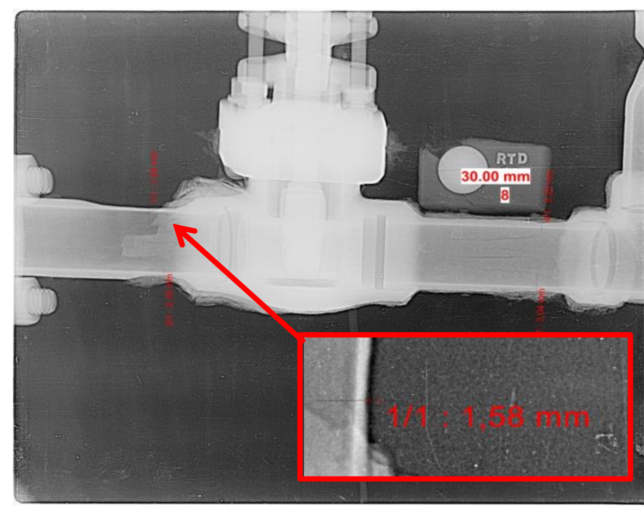
- Wrong (historical) design of the equipment and/or insulation
- Poor installation quality
- Longitudinal seams of weather protecting sheeting not correct orientated
- Critical locations specific to equipment designs, such as supporting / stiffener rings (static equipment) , foundations, saddles, supports, lifting lugs
- Supporting positions, flange locations, valves and end-points of insulation (vertical lines!)

Knowledge – CUI: critical spots

Design and concept related – Drains / Vents / Instrument connections

- Inspection departments have focus on large / critical lines
- Small bore piping (≤ 2”) often field fit-up and ‘forgotten’ in the inspection workload
- Small bore piping are more difficult to insulated due to large amount of direction changes and small dimensions
- Due to field fit-up small bore piping are often painted in non-ideal conditions (or even not painted!)
- In relation to equipment, the wall thicknesses used in these small bore piping configurations are rather thin, means that fewer amount of ‘spare’ material is available



Knowledge CUI – Corrosion Under Insulation

Activities for prevention

- No moisture and no electrolyt
- No direct connection between different materials
- No insulation (process, energy, protection, condensation)
- Correct treatment (corrosion protection)
  - Full (3-layer) painting system
  - Thermal Spray Aluminium (TSA)
  - Insulating coatings
- Correct insulation applications
  - Up-to-date company guidelines and/or according to CINI (and/or any other standard)
  - Supervision / inspection (QA/QC plan!)
  - Scheduled maintenance

Knowledge CUI – Corrosion Under Insulation

Other conditions or sources

➡ Applied coating protections – risks of failure?

Table 6 - *Evaluation of insulation systems*

Insulation system	Mineral wool	Mineral wool + Distance
Coating system A, UHPWJ, 15°C	Medium: 35-50%, B	Slight: 10%, B,
Coating system A, UHPWJ, 120°C	Heavy: 35-50%, B, poor top layer	Medium: 10%, B, poor top layer
TSA, Grit blasting, 15°C *	No: 0%, DFT = 170 □m	No: 0%, DFT = 260 □m
Coating system B, UHPWJ, 15°C	Heavy: 80-95%	No: 0%
Coating system B, UHPWJ, 120°C	Heavy: 95-98%	Slight: 0%, high DFT, b, loose top layer

* Loose top layer of Al-oxide removed by the tape during x-cut test

Table 7 - *Evaluation of coating systems*

Coating system	Coating system A	Coating system B	Phenol epoxy	TSA
UHPWJ, 15°C, spray, mineral wool	Medium: 35-50%, b	Heavy: 80-95%, b	No: 0%	
UHPWJ, 120°C, spray, mineral wool	Heavy: 35-50%, b, loose top layer	Heavy: 95-98%		
UHPWJ, 15°C, spray, mineral wool + distance	Slight: 10%, b	No: 0%		
UHPWJ, 120°C, spray, mineral wool + distance	Medium: 10%, b, loose top layer	Medium: 0%, b, loose top layer		
UHPWJ, 15°C, brush, mineral wool	40%, B	Heavy: 70%		
UHPWJ, 120°C, brush, mineral wool	Heavy: 40%, B loose top layer	Heavy: 60%		
UHPWJ, 15°C, spray, mineral wool, ½ DFT			No: 0%	
Grit blasting, 15 °C, mineral wool	Heavy: 80%, b	Heavy: 90%, b	No: 0%	No: 0%
Grit blasting, 15 °C, mineral wool + distance	Heavy: 70%			No: 0%
Brush, 15°C, spray, Mineral wool	Heavy: 95%, B	Heavy: 90%, b	No: 0%, b	
Brush, 120°C, spray, Mineral wool	Heavy: 95%			

Paper No.
10022

NACE INTERNATIONAL CORROSION 2010 CONFERENCE & EXPO

Corrosion under insulation - testing of protective systems at high temperatures

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Forskningsparken
NO-3908 Porsgrunn, Norway

ABSTRACT

Corrosion under insulation (CUI) has been a continuous challenge for on- and off-shore installations, requiring continuous focus on maintenance work. Pilot scale accelerated testing has been performed to study and evaluate the effects of CUI on different coating systems and service conditions. A test loop has been constructed, where 115 mm o.d. pipe spools were combined in a loop which is internally heated using steam. The coated and insulated pipe spools were exposed at controlled internal temperatures and intermittently wetted by fresh seawater. Two test lines with 8 pipe spools have been run in parallel.

Different aspects of CUI, including methods of steel pretreatment, coating application conditions, coating types and insulation design have been studied. Special focus has been on high temperature service conditions and the effect of moist and intermittently wet condition. High temperature coatings have been compared with a traditional coating system and thermally sprayed aluminum coating. The effect of coating application during service with steel temperatures up to 150°C has been studied.

Due to the harsh exposure conditions, both tested coating systems were heavily degraded and a fair comparison of the coating systems is difficult. A positive effect of distance insulation was the most significant result from the test, and both tested coating systems showed markedly improved quality using distance insulation. The different application temperatures showed significant differences, and the results were in general better for the coatings applied at ambient conditions. Only minor differences were observed between the different steel pre-treatment methods.

Key Words: Corrosion, insulation, high temperature, CUI

INTRODUCTION

Corrosion under insulation (CUI) has been a continuous challenge for on- and off-shore installations, requiring continuous focus on maintenance work. Pilot scale accelerated testing has been performed to study and evaluate the effects of CUI for different coating systems and service conditions. A test loop has been used, where 115 mm o.d. pipe spools are combined in a pipe loop that is internally heated using steam. The coated and insulated pipe spools are exposed at controlled internal

Roadmap to manage CUI

Critical aspects

- CUI can stay a long time out of sight, but when it comes to the surface, it is in most of the circumstances too late!!!!!!
- CUI causes Serious safety risks (e.g. leakages : ‘loss of content’, explosions, fire, personal injuries)
- CUI causes economical hick-ups (e.g. production loss, force majeur, customer complaints,...)

“It takes 20 years to build a reputation,

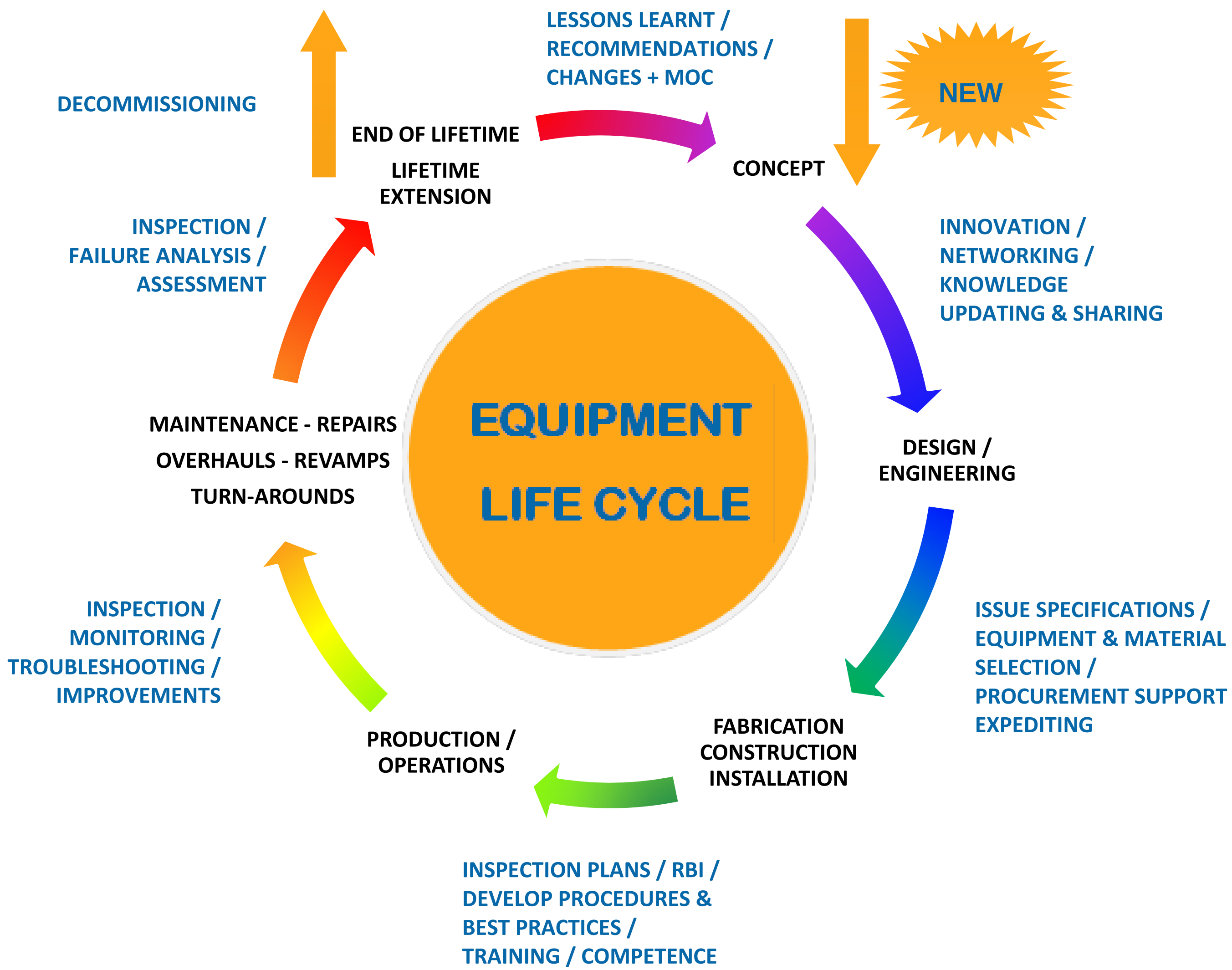
and five minutes to ruin it”

(Warren Buffett)

The basic rule

Avoiding CUI starts at the design and revamp/assembly of piping, equipment and structurals!

Roadmap to manage CUI



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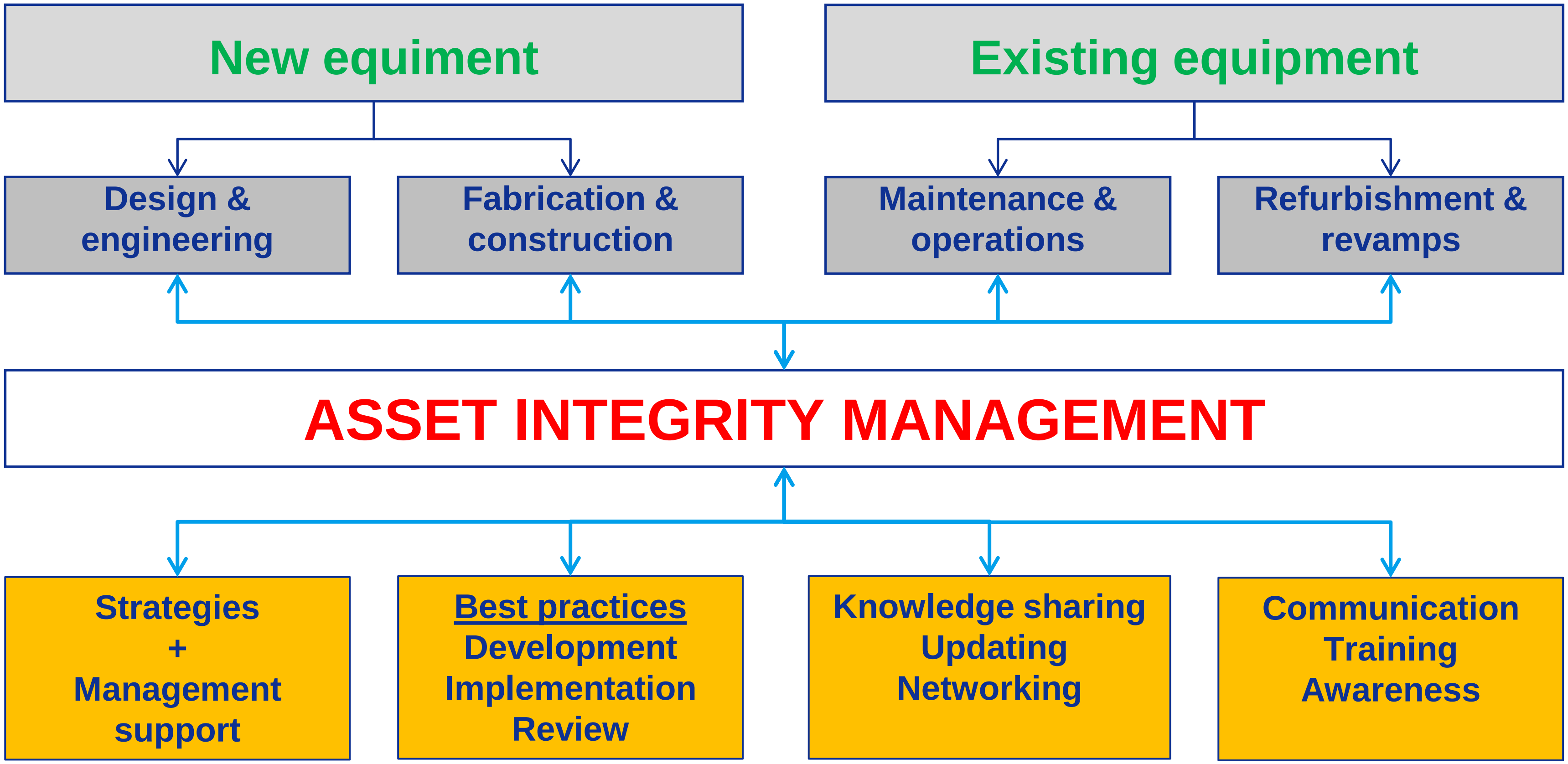
Roadmap to manage CUI

Necessary interactions to avoid CUI



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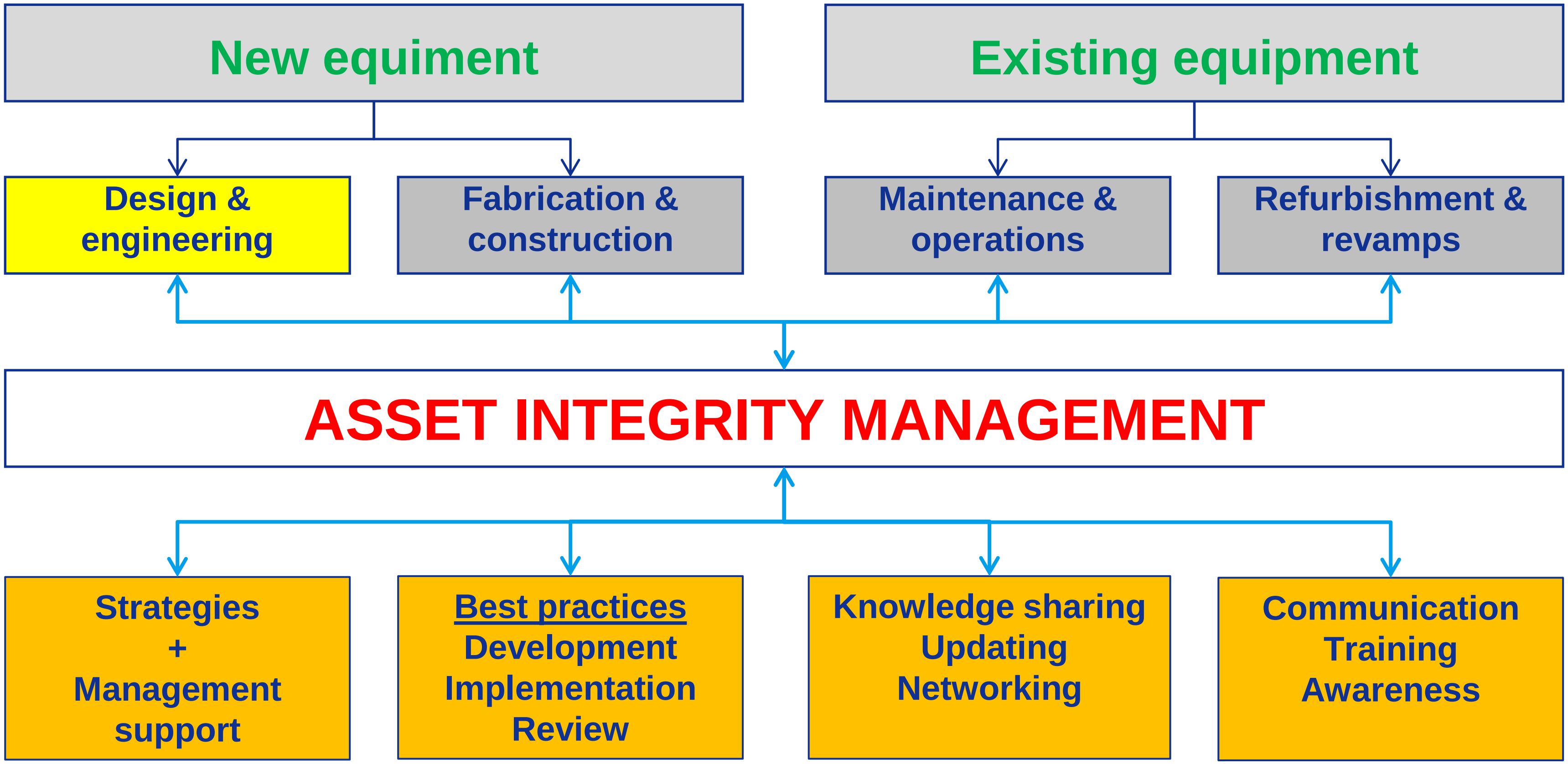
Roadmap to manage CUI

Necessary interactions to avoid CUI



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Roadmap to manage CUI

Design and engineering

- As earlier indicated - knowledge where CUI can occur is the primary key to succes
- Use of ‘best-practices’ and rules with proven results

Insulation systems

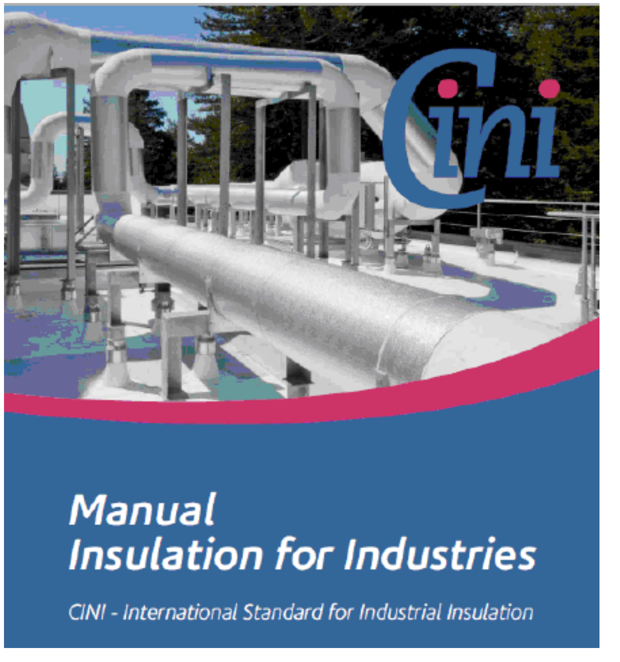
- and the applied painting system below the insulation! -

deserve more attention !!!!!

- International standardisation committees
  (Nace / ISO / Norsok / EIIF / Feci / …)

  ⇨ Definition by means of theoretical texts
  (low level of practical examples)

- Practical guide with proven ‘typicals’
  Cini is recognized on a global scale as one of the most up-to-date guidelines, created by end-users and applicators



The question is now is if end-users still need to develop their ow engineering specifications?

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Roadmap to manage CUI

Design and engineering

➡ Easy selection criteria (materials / operating conditions / HSE)

…. But what is now the best insulation set-up for my application?

CINI provides proven‘best practices’
The CINI comittees, with members from end-users, applicators and fabricators, are sharing knowledge and develop new typical solutions

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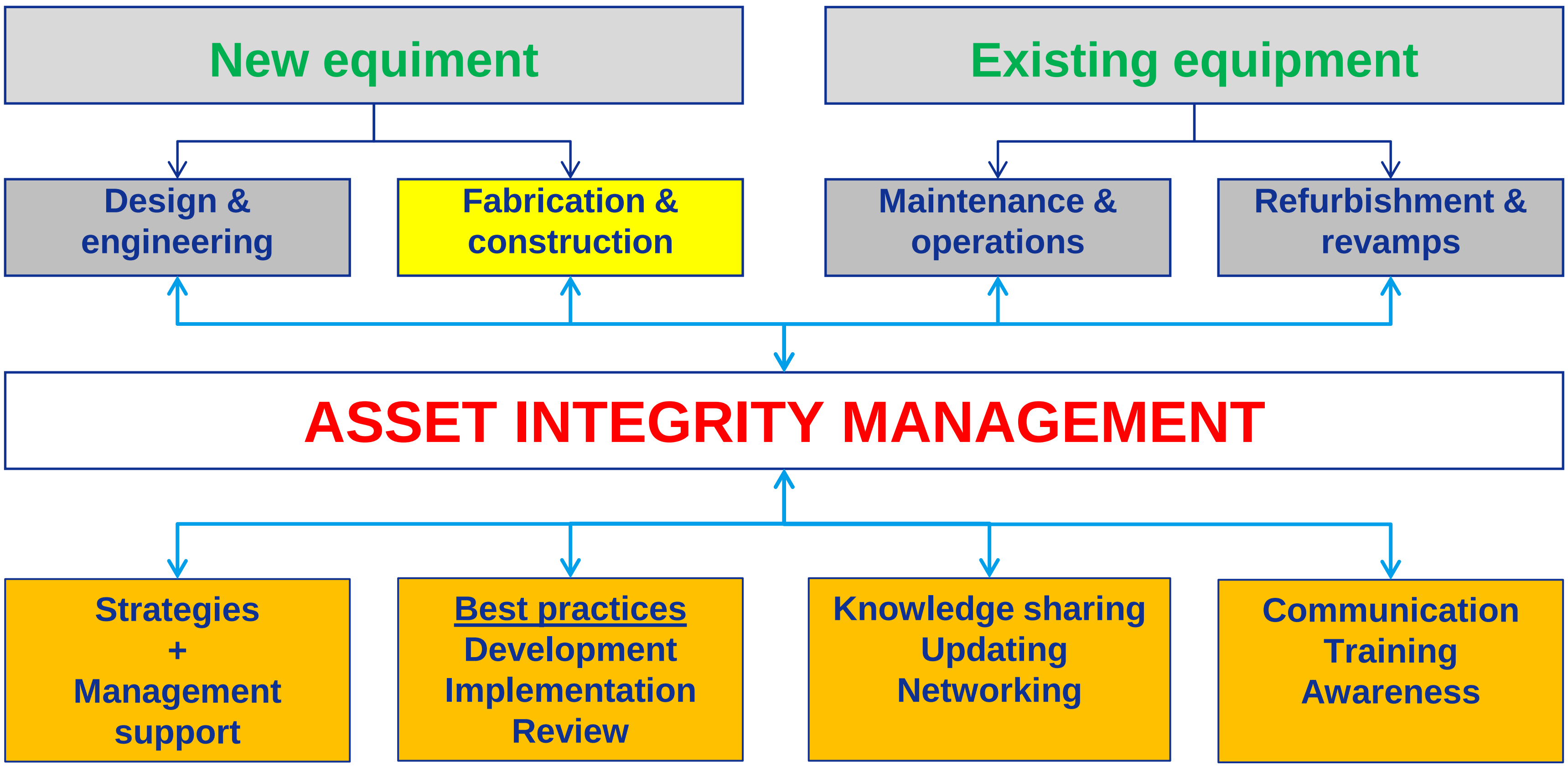
Roadmap to manage CUI

Necessary interactions to avoid CUI



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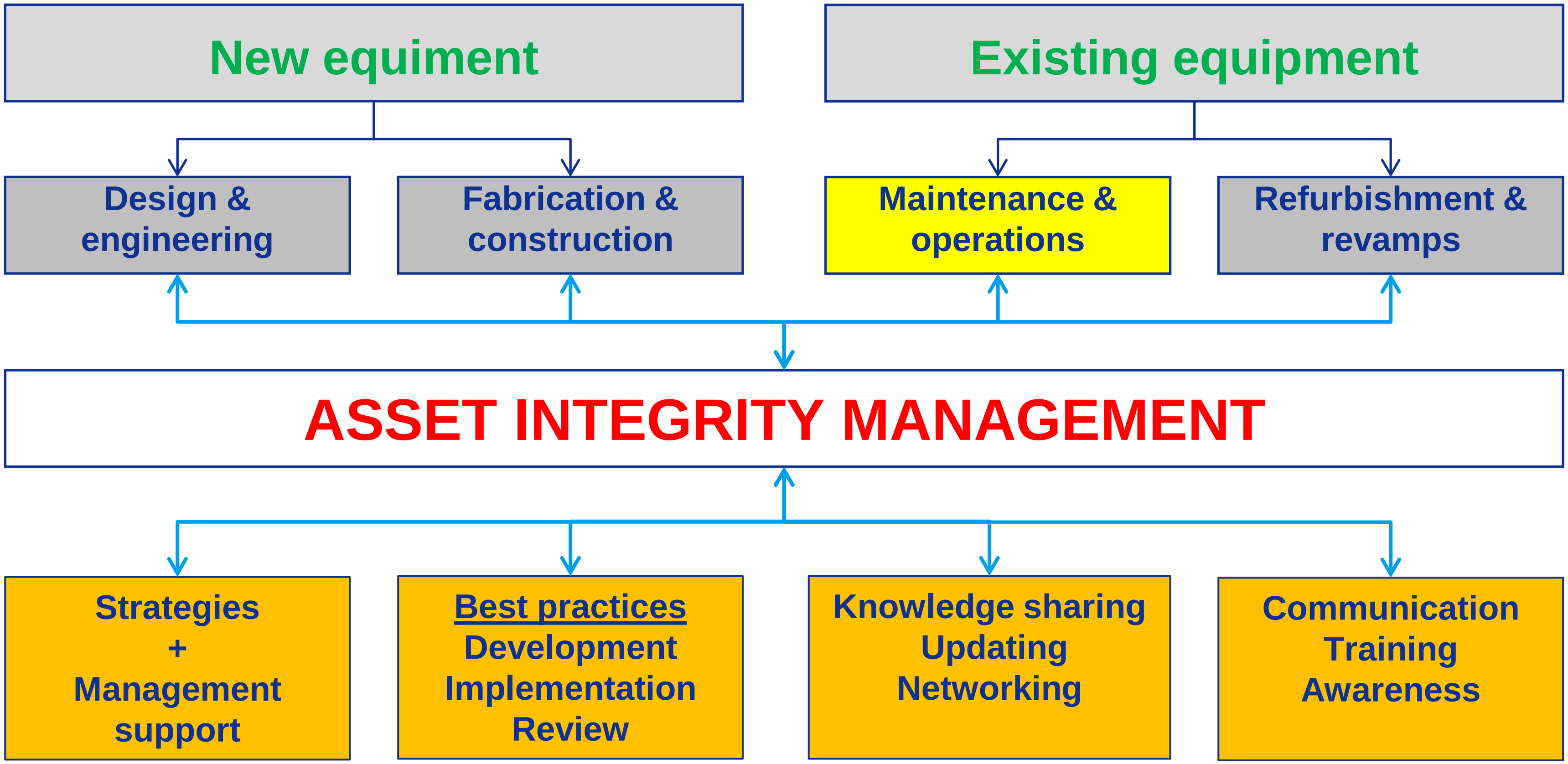
Roadmap to manage CUI

Necessary interactions to avoid CUI



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Roadmap to manage CUI

Necessary interactions to avoid CUI

Preventing & elimination of each CUI cause

- control of process conditions en IOW (Integrity Operating Windows)
- Prevent intrusion of water and/or humidity

- CUI Inspection- and repair program
- Risk- and damage restriction
- Surface protection / Coating !
- Keep insulation / coating in a good shape!!!!!

Existing equipment

- Maintenance & operations
- Refurbishment & revamps

ASSET INTEGRITY MANAGEMENT

- Strategies + Management support
- Best practices: Development, Implementation, Review
- Knowledge sharing, Updating, Networking
- Communication, Training, Awareness

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Roadmap to manage CUI

Surface protection = final layer of defence

Point 1 : preparation of the surface

- Blasting to SA 2,5 or SA3, depending on the paint supplier recommendations
- Very important step to assure a good adhesion of the paint to the surface

Point 2 : coating selection

- Avoid to apply Zinc-Rich coatings under insulation (NACE recommendation)
- Use TSA (Thermal Sprayed Aluminium)
    - ➢ Ideal in case of prefab of pipe spools and equipment
    - ➢ More problematic to use this for in-field applications
    - ➢ Design details to be adapted to avoid sharp edges and corners
    - ➢ Design shall allow good entrance of the spraying gun (angle of attack = 45-90°)

Point 3 : application of the coating

- Apply in accordance to supplier recommendations
- Respect temperature and humidity limitations
- Respect the amount of layers and the thickness of the applied layers
- Take care to follow the recommendations about drying times

Point 4 : inspection & QA/QC

- Ensure that the specifications and procedures are followed in practice
- Check continuously

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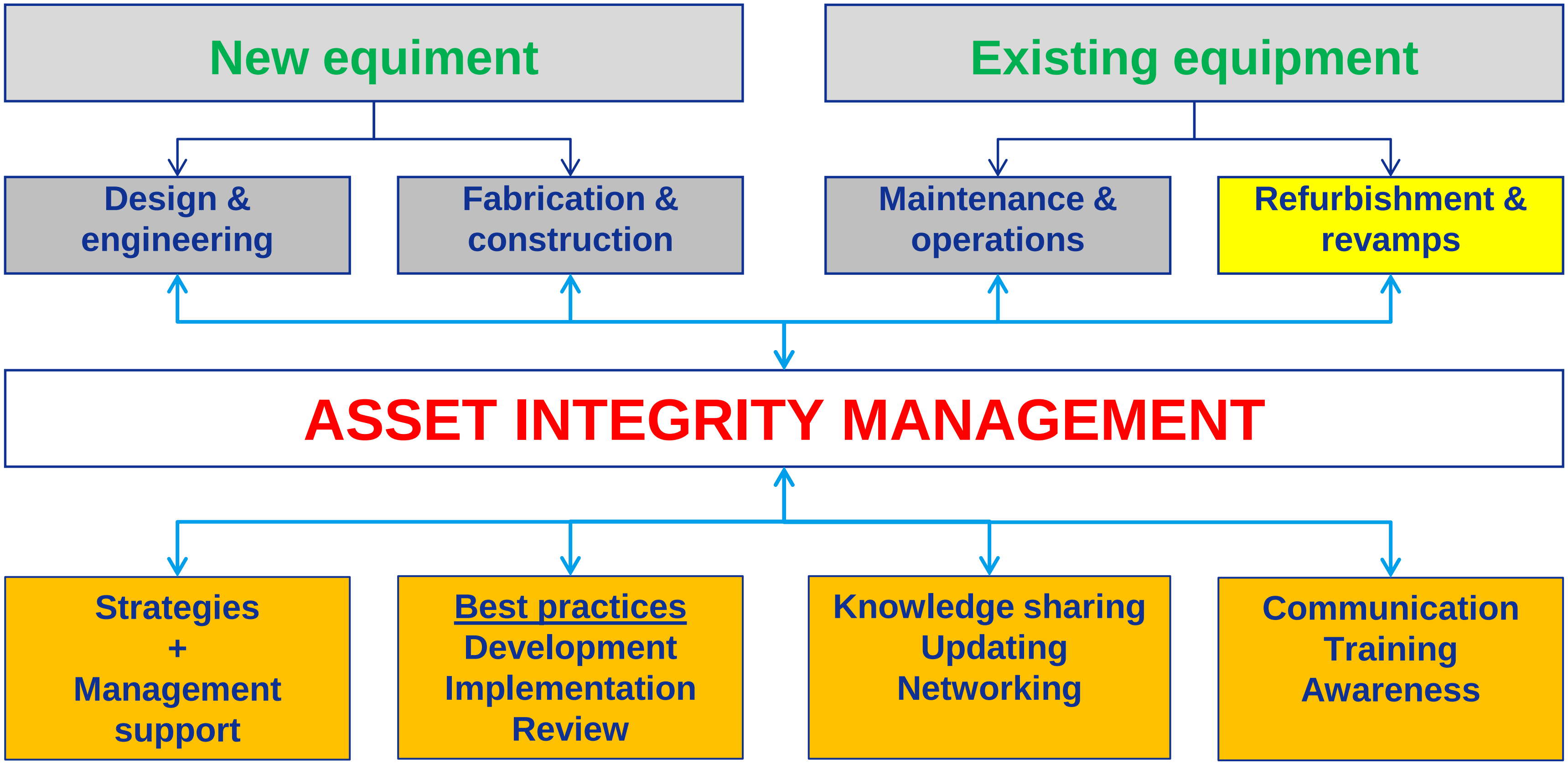
Roadmap to manage CUI

Necessary interactions to avoid CUI



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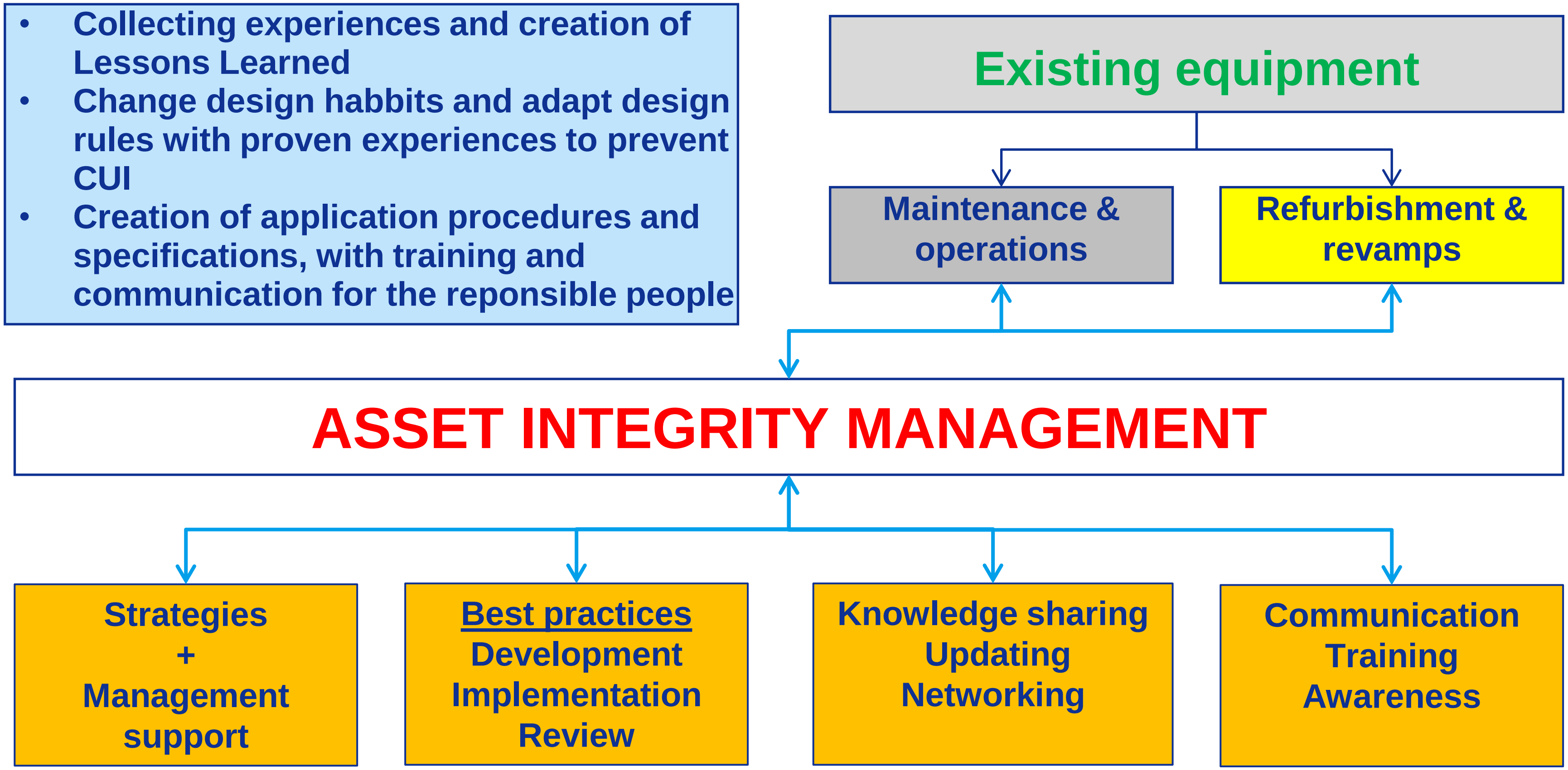
Roadmap to manage CUI

Necessary interactions to avoid CUI

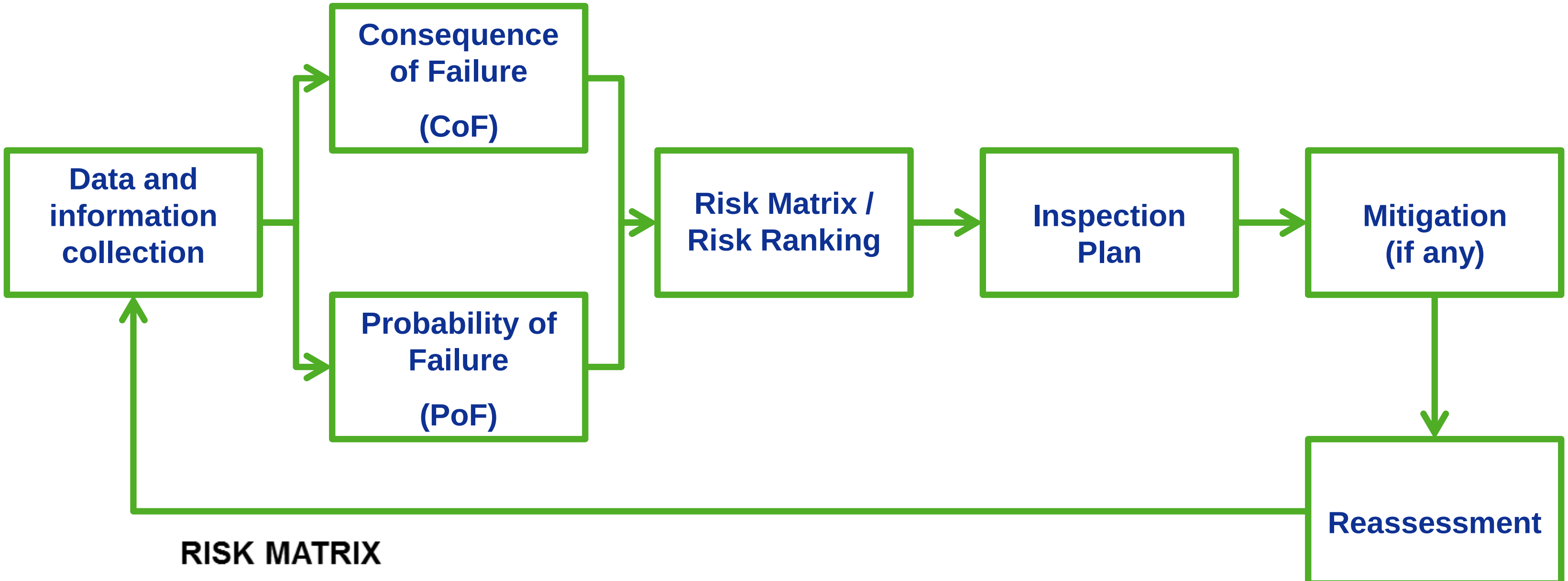
- **Collecting experiences and creation of Lessons Learned**
- **Change design habbits and adapt design rules with proven experiences to prevent CUI**
- **Creation of application procedures and specifications, with training and communication for the reponsible people**



Roadmap to manage CUI

Strategies & preventive measures

RBI (Risk Based Inspection)



RISK MATRIX

LIKELIHOOD CATEGORY	A	B	C	D	E
1	MH	MH	MH	H	H
2	M	M	MH	MH	H
3	L	L	M	MH	MH
4	L	L	M	M	MH
5	L	L	M	M	MH

CONSEQUENCE CATEGORY

RISK	CODE	CUI INSPECTION STRATEGY
HIGH	H	CUI-1
MEDIUM-HIGH	MH	CUI-2
MEDIUM	M	CUI-3
LOW	L	CUI-4

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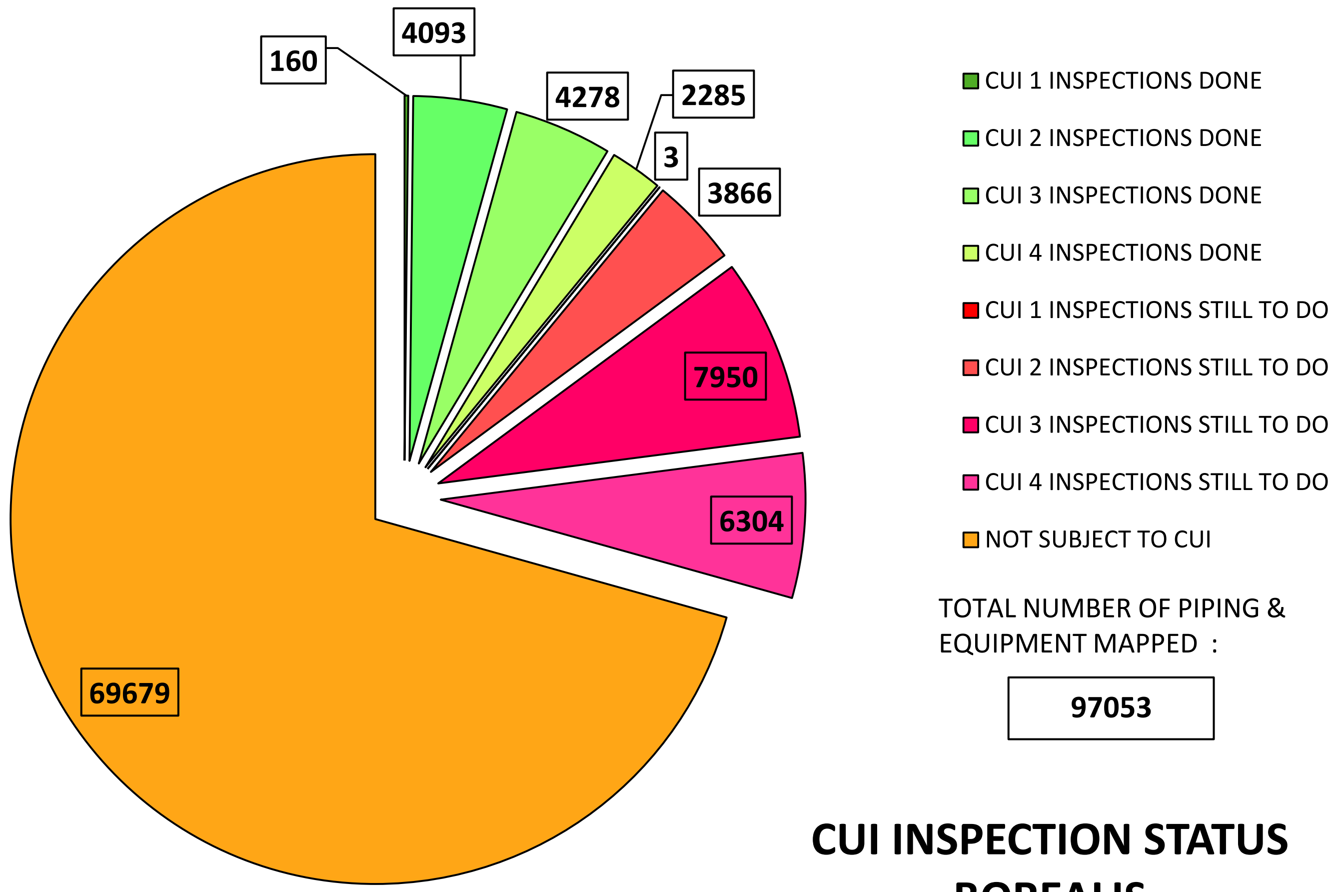
Roadmap to manage CUI

Strategies & preventive measures

RBI (Risk Based Inspection)



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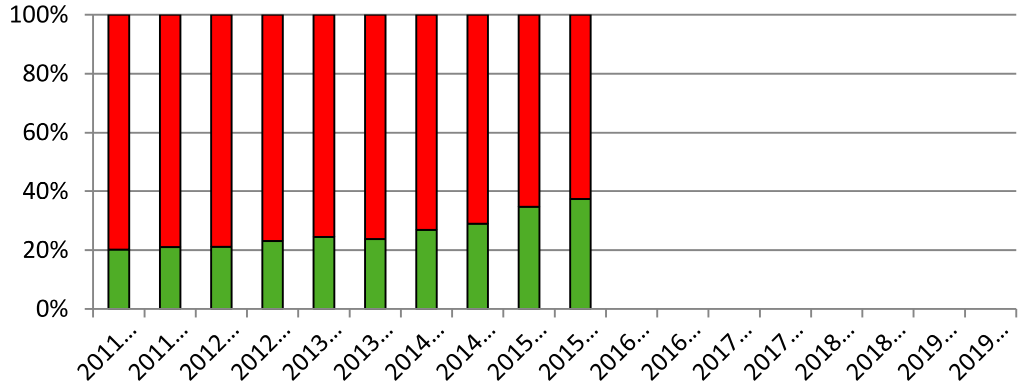
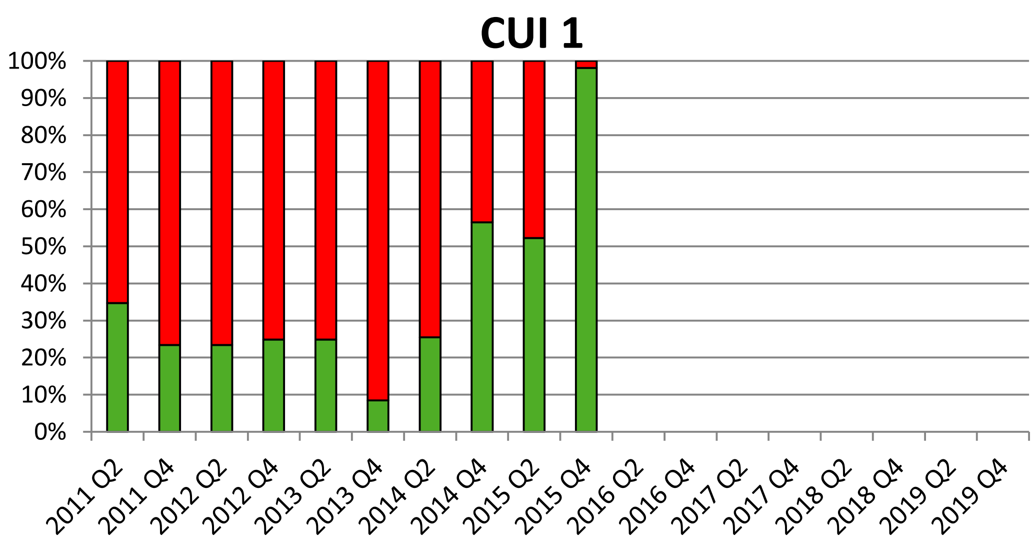
Roadmap to manage CUI

Strategies & preventive measures

RBI (Risk Based Inspection)





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Roadmap to manage CUI

'CUI – preventing actions

Point 1 : NO insulation = NO CUI!!!

- Check for alternatives in case insulation is required (cages / insulation coatings (PP applications)

Point 2 : Adapt your designs, based on proven experiences to avoid CUI

- Avoid points of water intrusions
- Avoid water collecting points

Point 3 : Use a qualitative painting system for new and existing parts as final line of defense

- QA/QC of application, with up to date specifications and procedures
- Integrate re-painting works as part of normal maintenance activities

Point 4 : Inspect existing insulation & avoid damaging by secondary maintenance activities

- Awareness of all people to 'respect' the insulation – DON'T STEP ON IT!
- Replacement strategy, without long waiting process
- Inspection of insulation & painting shall be performed on the same level as it is for welding

Roadmap to manage CUI

‘CUI – preventing actions

Point 5 : Application in accordance with best practice rules

- Keep awareness about the details and the quality of application

Point 6 : Creation of action plans – RBI (Risk Based Inspection)

- Interaction required between engineering – production – maintenance - inspection

Point 7 : Evaluation & exchange of experiences

- Intercompany, but even more important is also to check external resourses

Point 8 : Continuous observation / mandatory declaration for every member of the staff

- Alert / Attentive / Careful

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Roadmap to manage CUI

‘CUI – tackling actions

Step 1 : Start with Fitness-for-Service (FFS)

- Based on API 579-1 ⇨ determine of the Minimum Allowable Wall Thickness

Step 2 : wall thickness = OK ⇨ apply new coating and insulation

- Check if insulation is really necessary
- Check alternatives
- Use QA/QC plans to check application actions

Step 3 : wall thickness ≠ OK ⇨ repair or replace

- In case of a temporary repair, an in detail risk analysis is mandatory
- Re-evaluate the original design and modify to best practices

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Thank you

Appendix 13

High quality electroslag strip cladding of thin single layers for 625 alloy

(F. Ciccomascolo)

High quality electroslag strip cladding of thin single layers for 625 alloy

Mathieu Decherf
Ronny Demuzere
Francesco Ciccomascolo

Why strip cladding ?

One single material cannot
comply with all the specifications

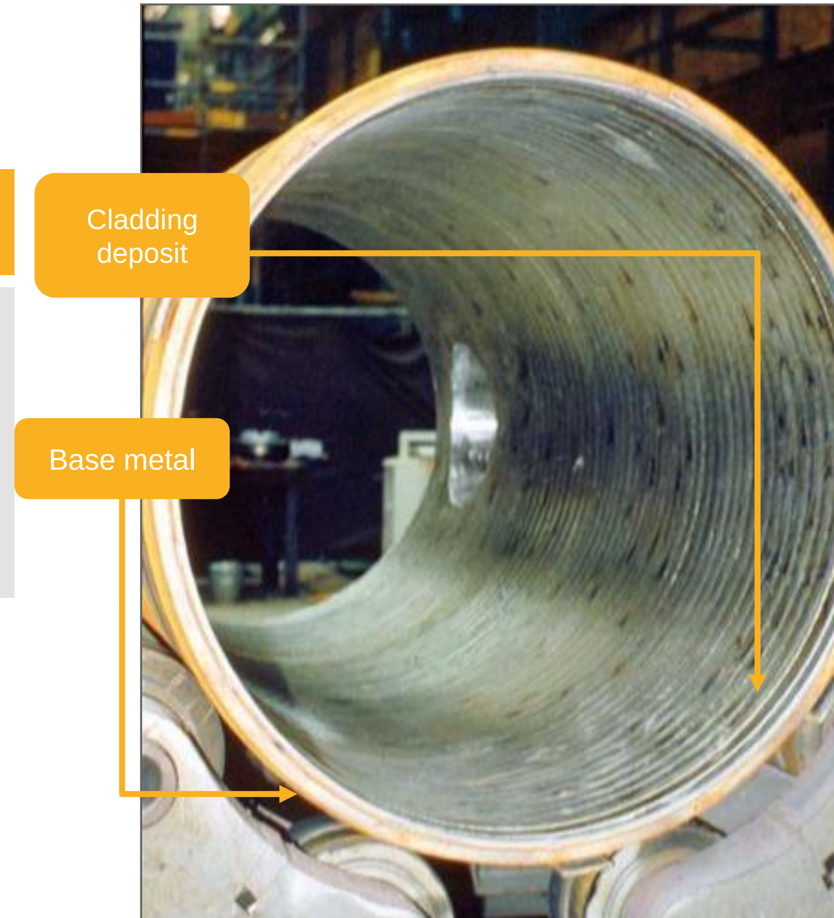
Solutions : combining two materials

Outside : unalloyed steel for mechanical properties

Inside : alloyed or low alloyed Cladding for anti-wear and anti-corrosion properties

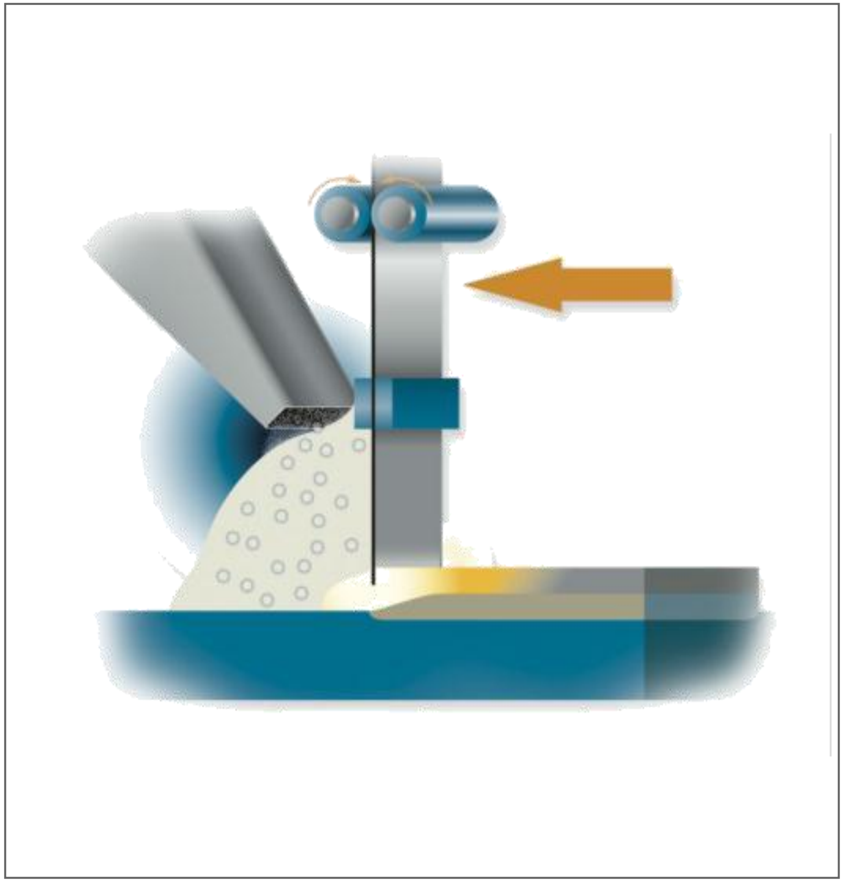
Strip cladding

- Submerged arc
  SASC
- Electroslag
  ESSC



Electroslag strip cladding

- Special welding flux
- One side flux feeding
- No electric arc
- Electroconductive slag
- Open weld pool



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Oil & Gas and Chemical Processing industry

- One of the most common alloys :
  - Alloy 625 clad on ASTM SA516 Grade 55, 60, 65, 70

Alloy 625
Oil & Gas and Chemical Processing (strip cladding)

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Subsea Separator / Shell and dish-ends

Customer/ Fab. Shop: CMP Arles, France

Base materials: P500 QL2

- weight 190 tons
- Outside diameter 3600 mm
- thickness 96 mm
- length 15 m

Filler metal:

- Soudotape625 / 60x0,5 mm, 21000 kg
- Flux record EST625-1, 14700 kg
- Single layer deposit: 5,5mm

Engineering: FMC-Norway

Owner : TOTAL

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Productivity improvement

utp maintenance
by voestalpine

Demand for higher productivity

Two solutions (state of the art)

Lower number of layers	single layer fluxes
Higher deposition rates	high speed fluxes

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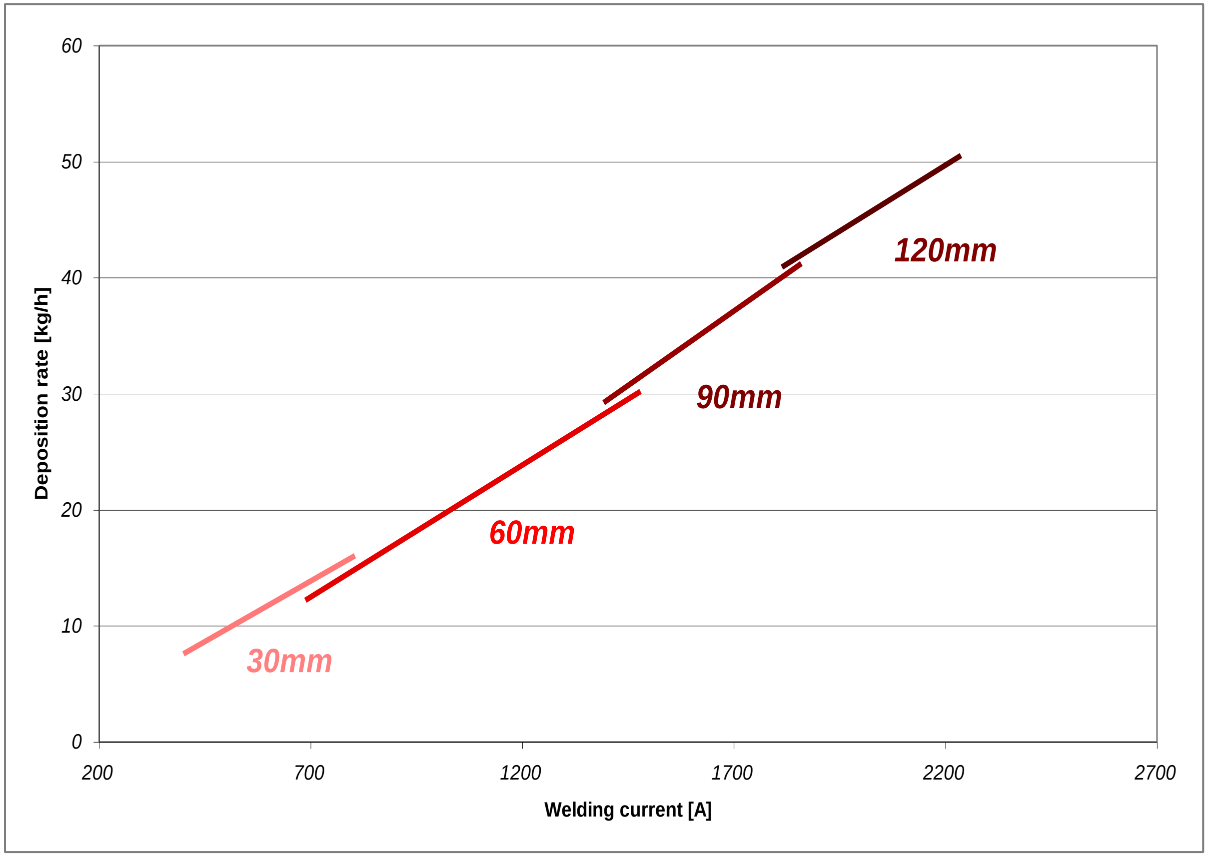
Productivity improvement



Productivity improvement through the strip requires :

- additional investment in expensive equipment
- a matching geometry of the component to be cladded

What can vaBW offer ?

- Innovative products
  - Thinner layers
  - Higher travel speed

INNOVATION : RECORD EST 625-1 LD

- Electroslag flux for 625 strip cladding allowing to deposit:
  - Fe < 7% in **one layer**
  - Fe < 10% in a **thin** single layer

Benefits of RECORD EST 625-1 LD

- Fe < 10% - thin single layer

	C	Mn	Si	Cr	Ni	Nb	Mo	Fe	1 layer thickness
RECORD EST 625-1 SOUDOTAPE 625 Single layer	0.025	0.20	0.30	21.5	-	3.5	9.0	**7.9**	**5.0mm**
RECORD EST 625-1 LD SOUDOTAPE 625 Single layer (Fe < 10%)	0.022	0.12	0.35	22.4	-	3.6	9.7	**8.0**	**3.6mm**

➔ Strip saving up to ~25%

Welding parameters (60x0,5mm strip) :

- Standard 625 single layer : 1250 A / 24 V / 20 cm/min
- RECORD EST 625-1 LD : 900 A / 24V / 18 cm/min

Benefits of RECORD EST 625-1 LD

- Fe < 7% - single layer

	C	Mn	Si	Cr	Ni	Nb	Mo	Fe	Total thickness
RECORD EST 201 SOUDOTAPE 625 Two layers cladding	0,020	0,10	0.30	21.5	-	3.0	8.8	2.5	8.4mm
RECORD EST 625-1 LD SOUDOTAPE 625 Single layer (Fe < 7%)	0.019	0.12	0.32	22.3	-	3.6	9.6	6.1	5.0mm

➔ Only 1 layer

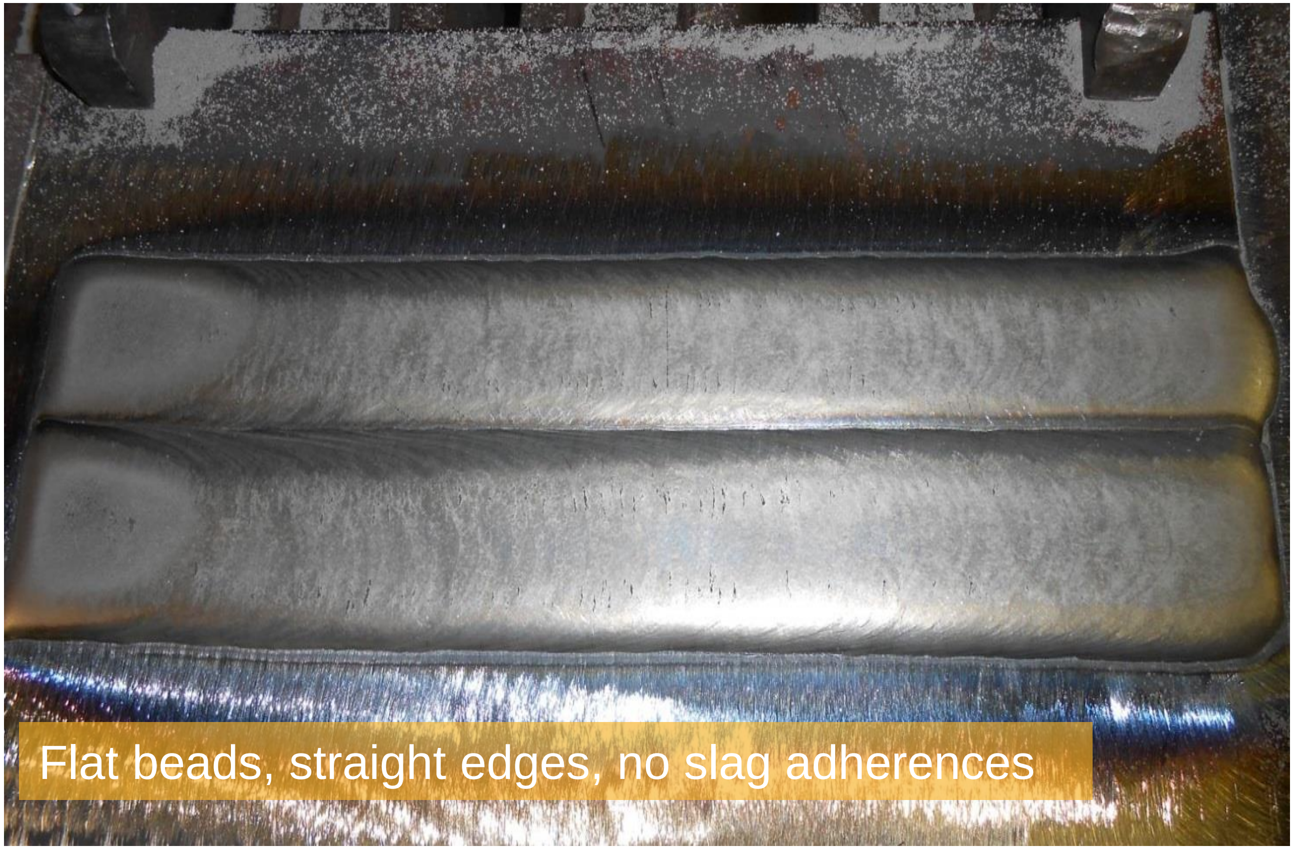
Welding parameters (60x0,5mm strip) :

- Standard 625 two layers : 1100 A / 24 V / 16 cm/min
- RECORD EST 625-1 LD : 1150 A / 24 V / 16 cm/min

Slag detachability

Easy slag removal

Beads appearance



Field test

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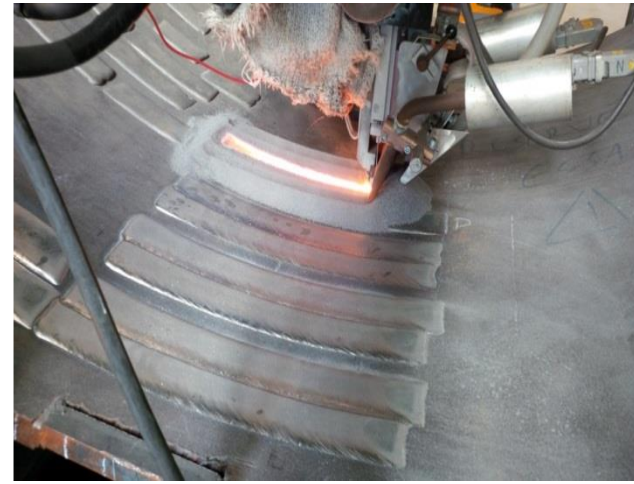

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Corrosion tests

RECORD EST 625-1 LD

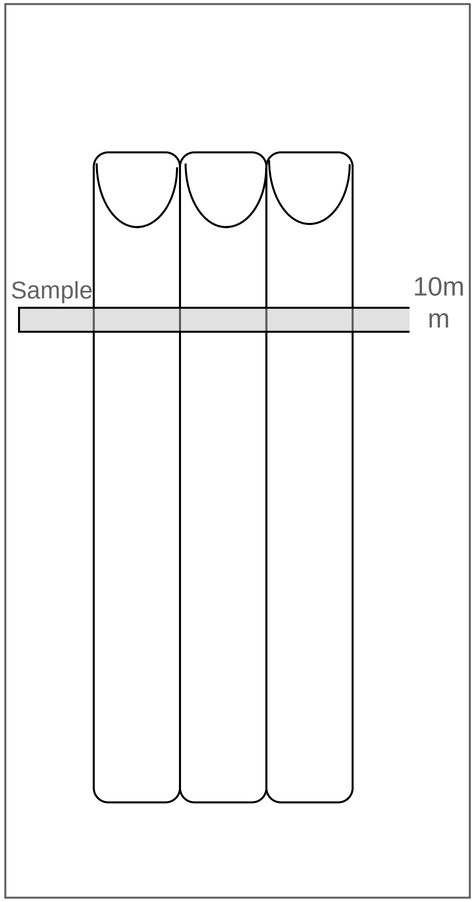
	Corrosion rate
ASTM G48A (72h @ 50°C)	0 mm/yr
ASTM G48A CPT [°C]	84
ASTM G28A (120h) Middle of the bead	0,53 mm/yr
ASTM G28A (120h) Overlap	0,42 mm/yr

RECORD EST 625

	Corrosion rate
ASTM G48A (72h @ 50°C)	0 mm/yr
ASTM G48A CPT [°C]	85
ASTM G28A (120h) Middle of the bead	0,68 mm/yr
ASTM G28A (120h) Overlap	0,65 mm/yr

Side bend tests

	As welded	After 24h@670°C
Sample thickness	10 mm	10 mm
Bending angle	180°	180°
Mandrel dia.	40 mm	40 mm
Remark	No crack	No crack



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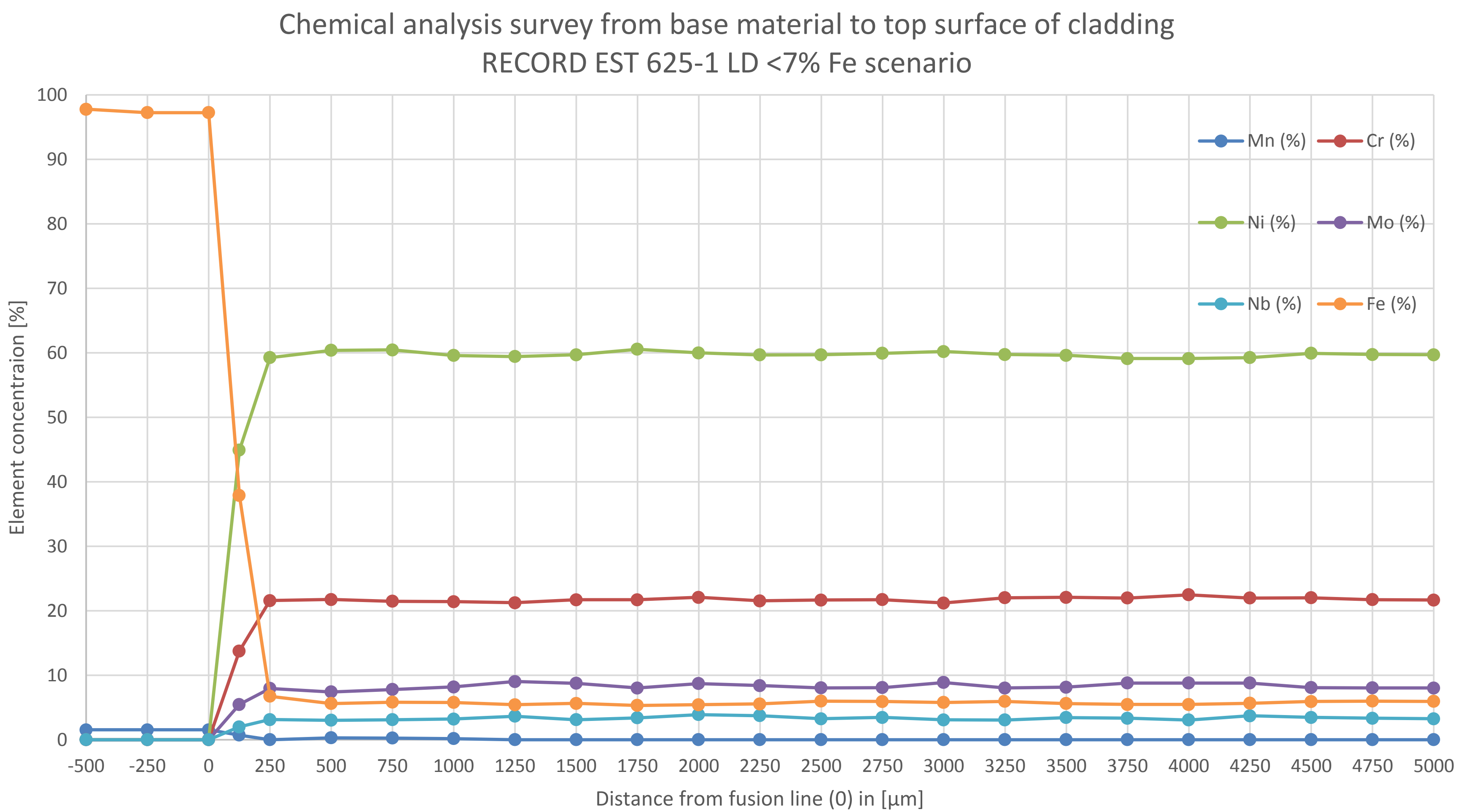
Chemical analysis survey



Macrography

Bead profile
Flat surface & fusion line
Defect free
Total thickness of 5,16 mm
Geometrical dilution of 5.8%

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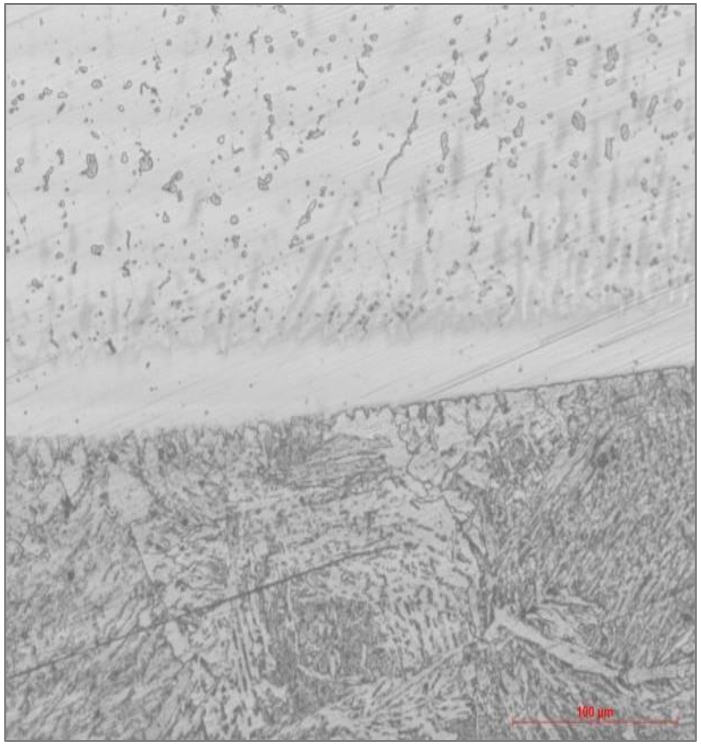
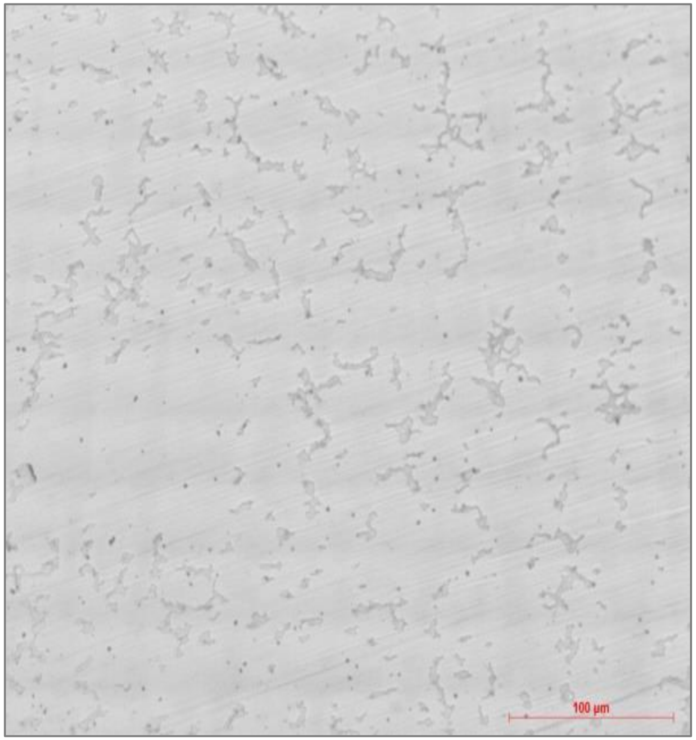
Microstructure





RECORD EST 625-1 LD cladding as welded. From left to right: fusion line area, middle of the bead.
Austenitic matrix with some Mo precipitates typical for Alloy 625 - Electrolytic etching 10% Cr_2O_3

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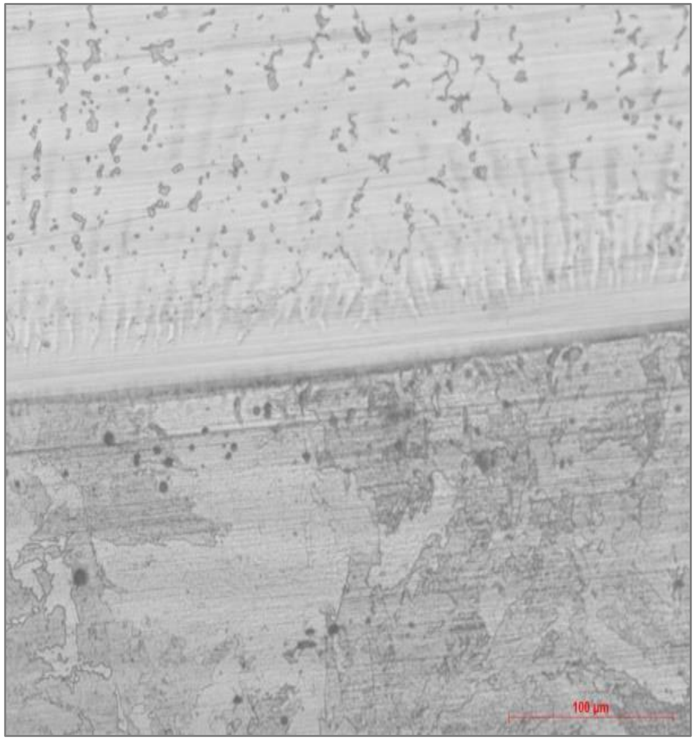
Microstructure



RECORD EST 625-1 LD cladding after PWHT (24h @ 670°C). From left to right: fusion line area, middle of the bead. Austenitic matrix with some Mo precipitates typical for Alloy 625 - Electrolytic etching 10% Cr_2O_3

Conclusions

New ESSC solutions for the thin single layer cladding of Alloy 625 has been developed.

Alloy 625 composition with Fe < 10% requirement can be realized in a thin single layer with reduced thickness

Alloy 625 composition with < 7% requirement can be realized in a single layer, where two layers are needed for the traditional industry solution.

The new ESSC strip / flux solutions account for major time savings in terms of clad surface in meters / hour and for savings in strip / flux consumption and satisfy all mechanical and corrosion requirements laid down in various standards relevant to the industry.

Thank you!

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