Casting the Die;
Implications of Zinc for Pressure Part Integrity

Paul James
Uniper Technologies Limited
Engineering for the Energy Evolution

November 2021

Uniper at a glance

Our operations

- Power Generation
- Commodity Trading
- Energy Storage
- Energy Sales
- Energy Engineering

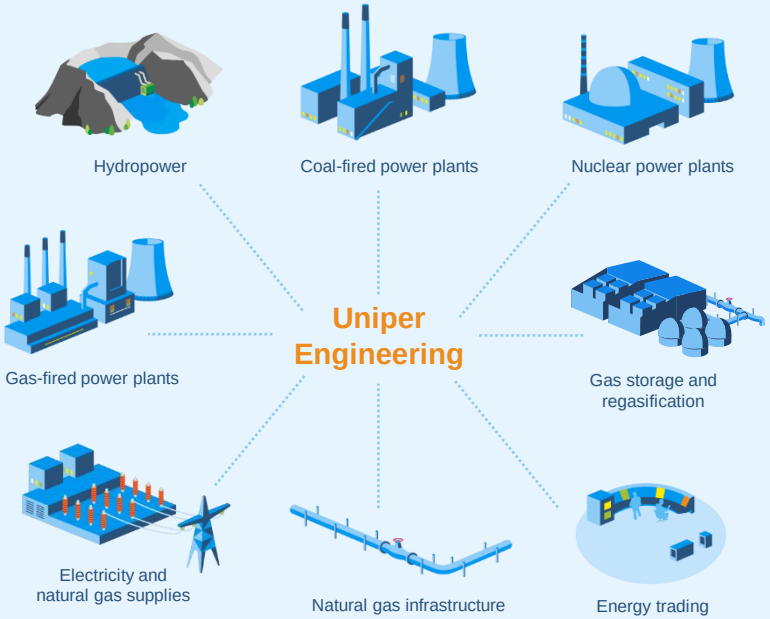
€998 mln.
Adj.EBIT[1]

~11,700
Employees

>40
Countries

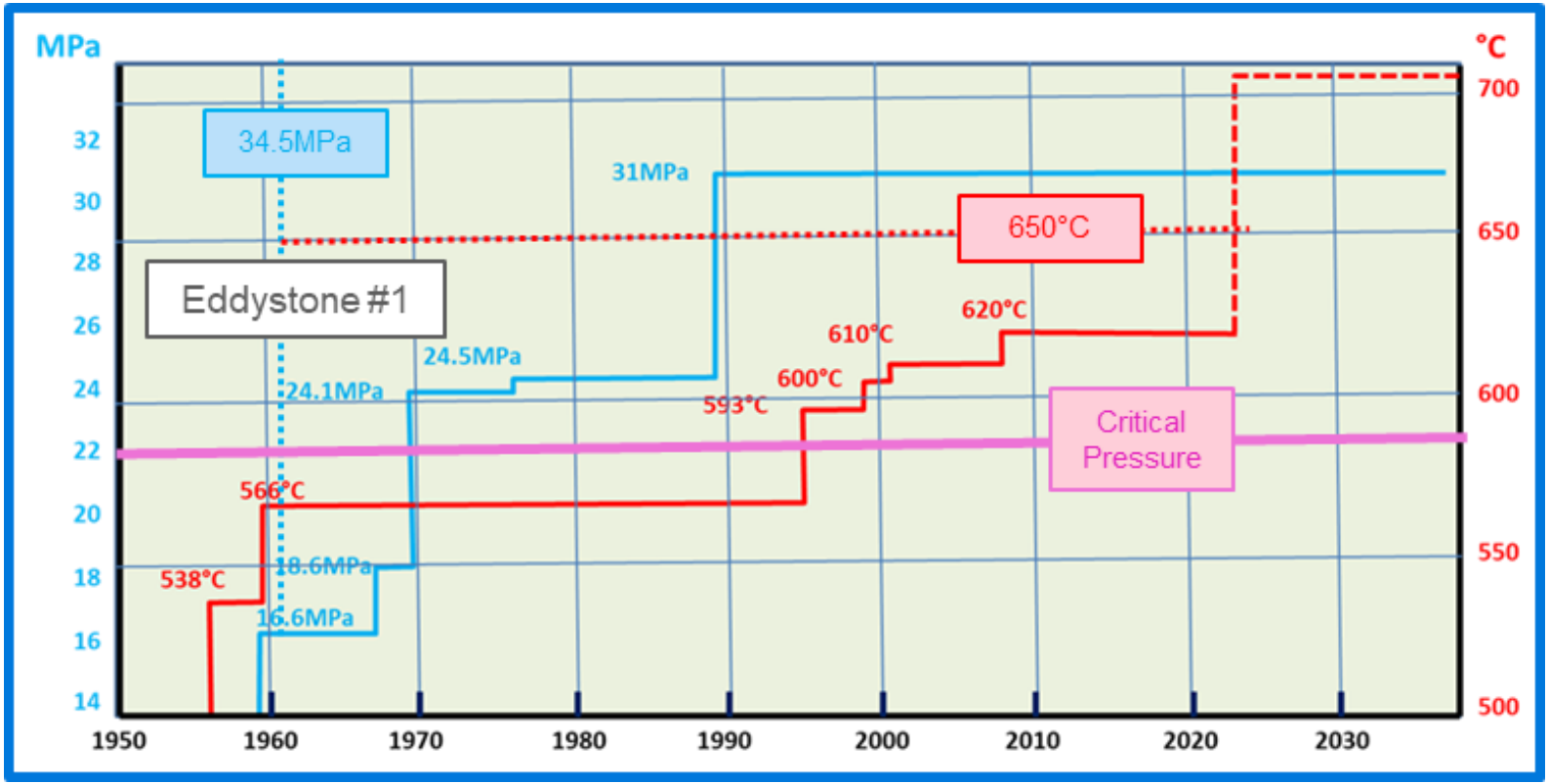
~35 GW
Generation capacity[1]

100+
Years' experience



1 As of December 31, 2020

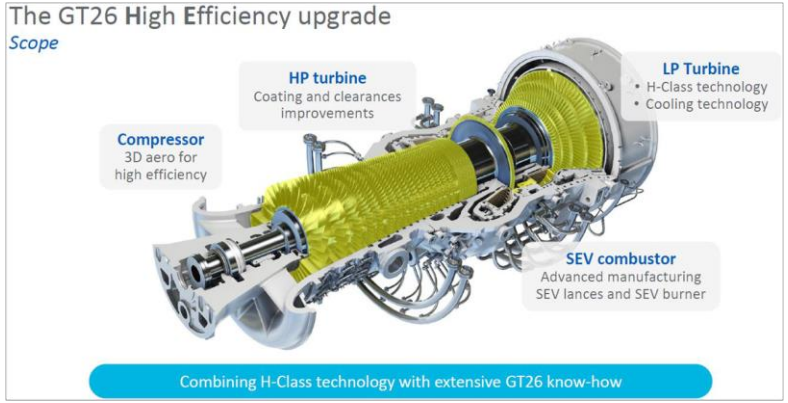
The Journey

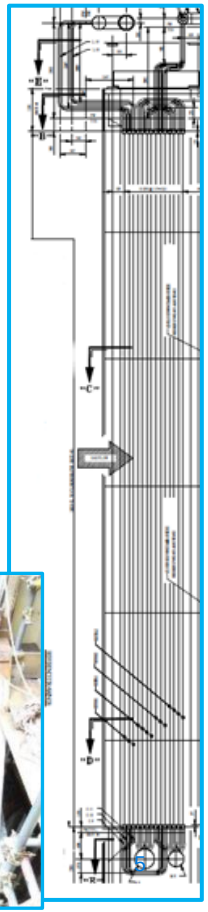


Post-1950 Boiler Plant Evolution

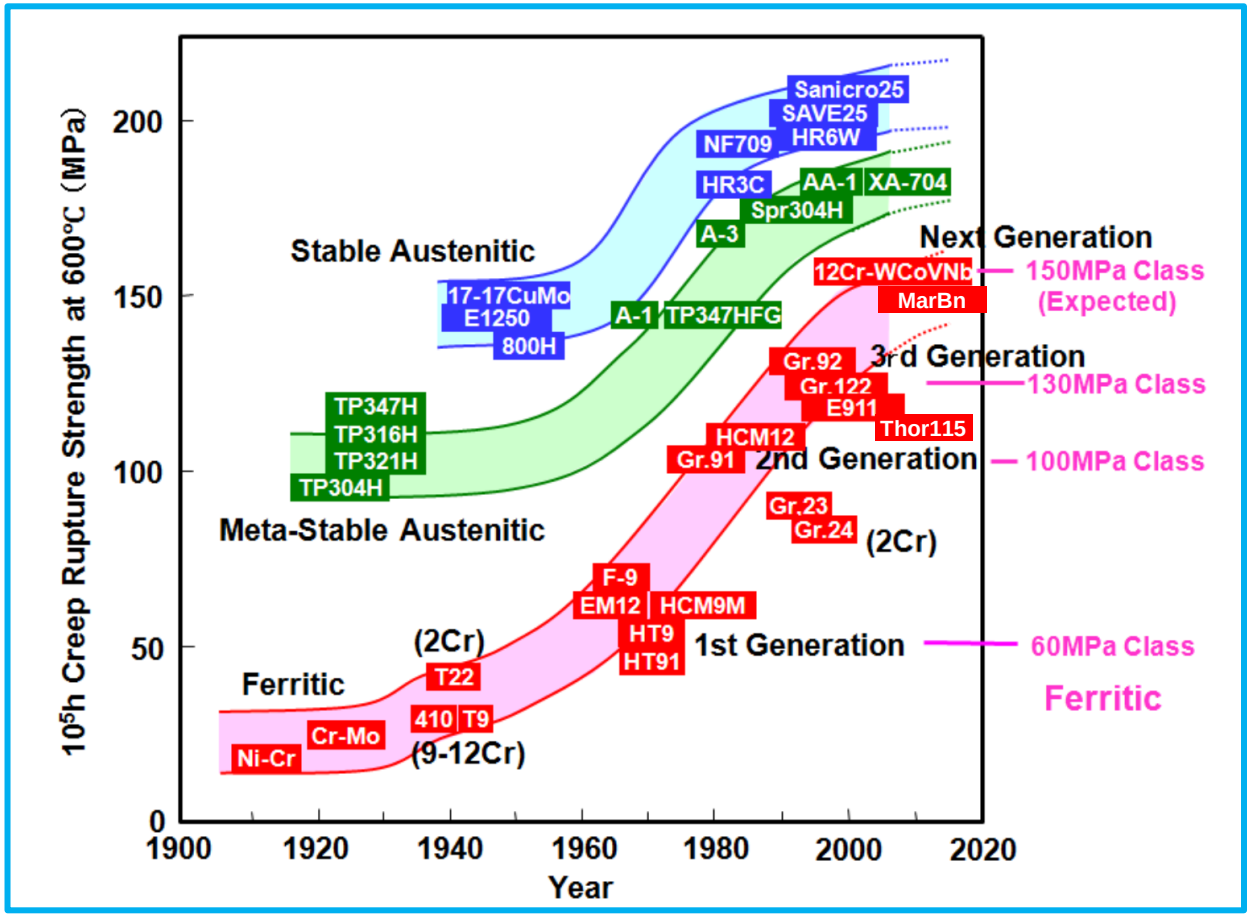
Integrity Implications of GT Upgrades

- The next generation of ‘High Efficiency’ gas turbines has already arrived.
- A recent upgrade of a GE GT26 turbine at a Uniper CCGT plant;
  - Returned better than 2.5% efficiency improvement (>58%)
  - Increased output from 408MW to 450MW
  - Increased the gas outlet temperature (TAT2) from ~620°C to 650°C
- Integrity implications for existing final superheater in Grade 91 with creep life already part consumed
- Decision taken to upgrade stage to Grade 92 to anticipate operation to 2030, and potentially beyond.



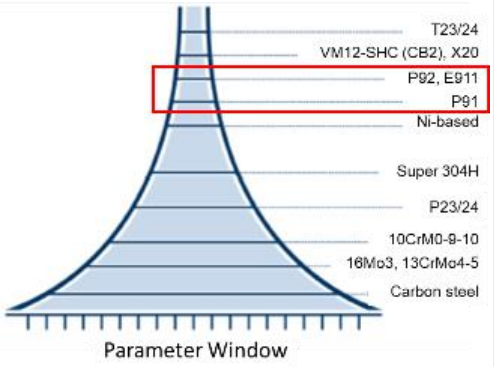


The Future



Metallurgical déjà vu?

- The dual challenge of operating with increased operating pressures and temperatures, demanding improved mechanical and corrosion performance, has been met through the use of ferritic steel grades more sensitive to fabrication controls than more traditional grades.
- The introduction of austenitic stainless steels to meet similar requirements in the 1940s/1950s saw major issues with weld cracking local to outlet headers, at transitions & welds in the main steam pipework – damage responsible for a losses of £4m (~£50m-2015) during the 5-years to 1959. Resolved by;
    - Changing weld consumable from low ductility T347 (Nicrex) to a T316 based alternative (Armex).
    - Modified stress relief procedure for pipework thicker than 25mm (5”).
    - Improved weld inspection procedure and post-weld surface dressing.



Material Sensitivity to Fabrication Parameters

- N&T Temperature & duration
- Post-manipulation heat treatment
- Pre-heat temperature
- Inter-pass temperature
- Welding technique
- Welding current/voltage
- Welding speed
- Weld bead layering
- Weld bead size

Anomalous Behaviour

Premature failure of a P91 header endcap.

Rogue PWHT leading to SCC failure within 48 hours.

Consequences of applying traditional techniques on T91 tubing.

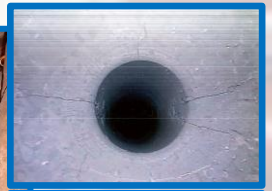
Detrimental impact of transient thermal excursions on component integrity.

Steamside spalling and implications for downstream components.

Anomalous Behaviour

Problematic design features hindering inspection

Access constraints

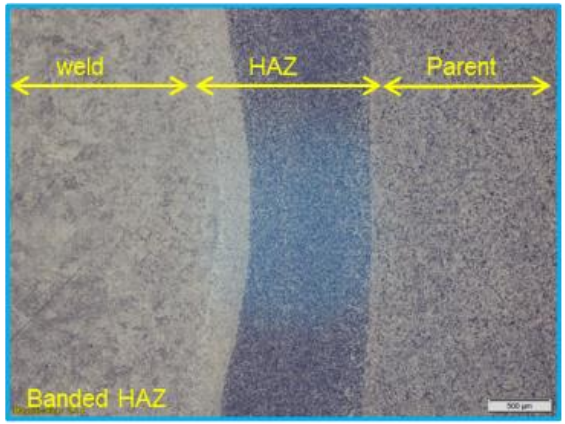


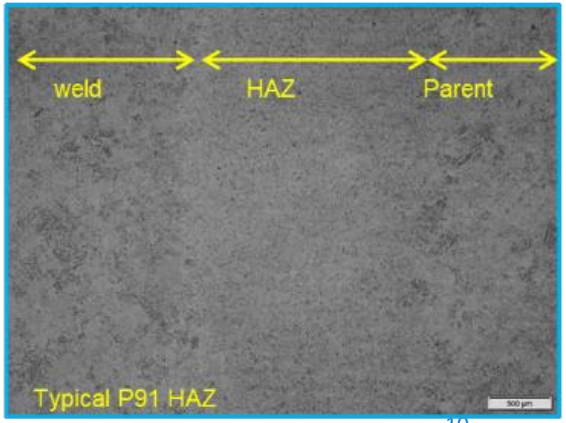
P22 vs P91,
which is better?

Effect of Zinc paint on P91 HRSG components

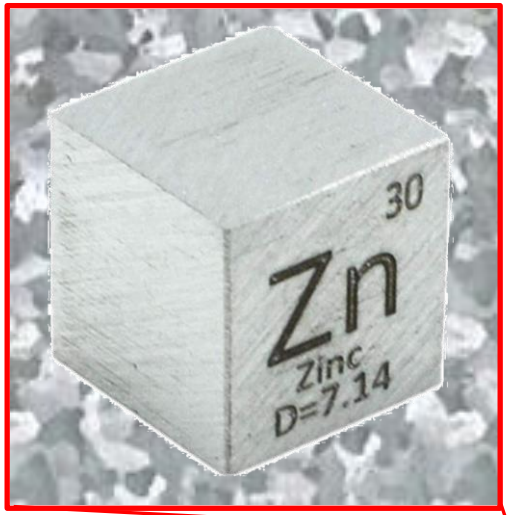
Zinc Concerns; The Backstory

- 2016; Replicas taken from Grade 91 Steam Outlet Branch in a UK CCGT plant revealed a dark etching band adjacent to a weld.
- Analysis confirmed the dark band to be Zinc enriched.
- Rather than the typical “red oxide” coating, the component had been originally coated with a Zinc paint (ethyl-silicate-based elemental Zinc paint) – not unusual!
- Dark band was fully circumferential and exhibited apparent evidence of creep cracking/cavitation, albeit confined to a narrow arc centered on the flank position (Type IV).

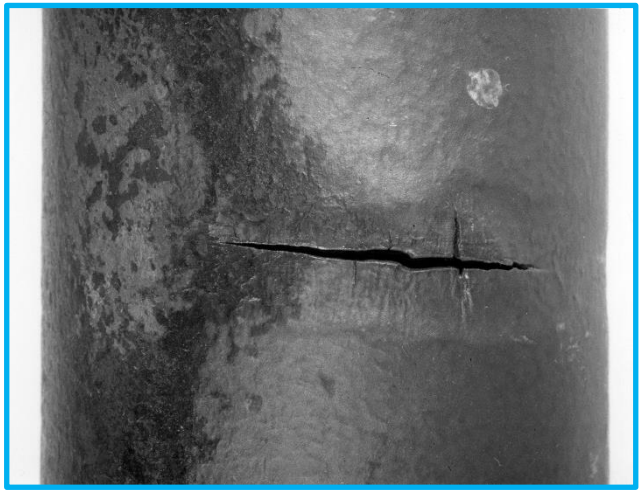




Why concerned about Zinc?



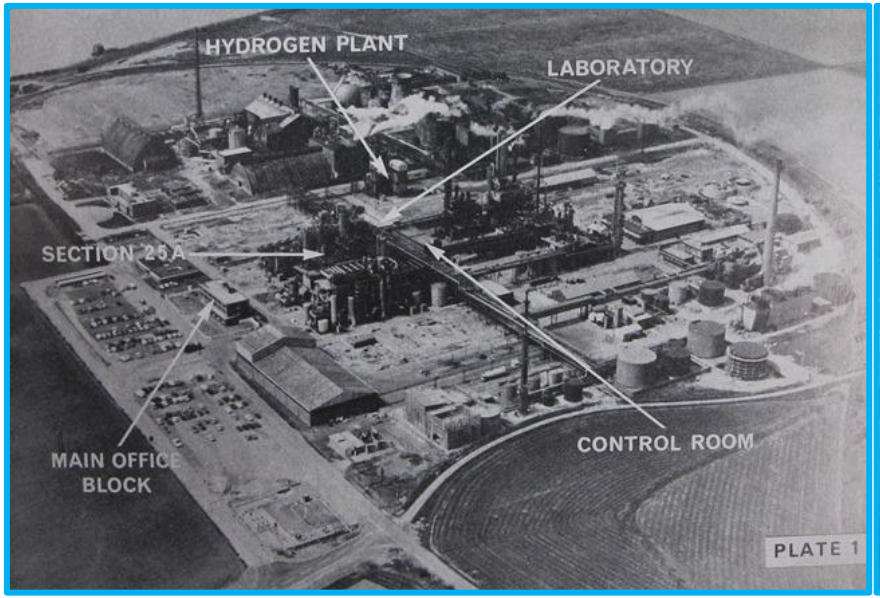
- Bluish-white metal.
- Some ductility.
- Relatively poor corrosion performance, ideal sacrificial behaviour!
- MP = 420°C.

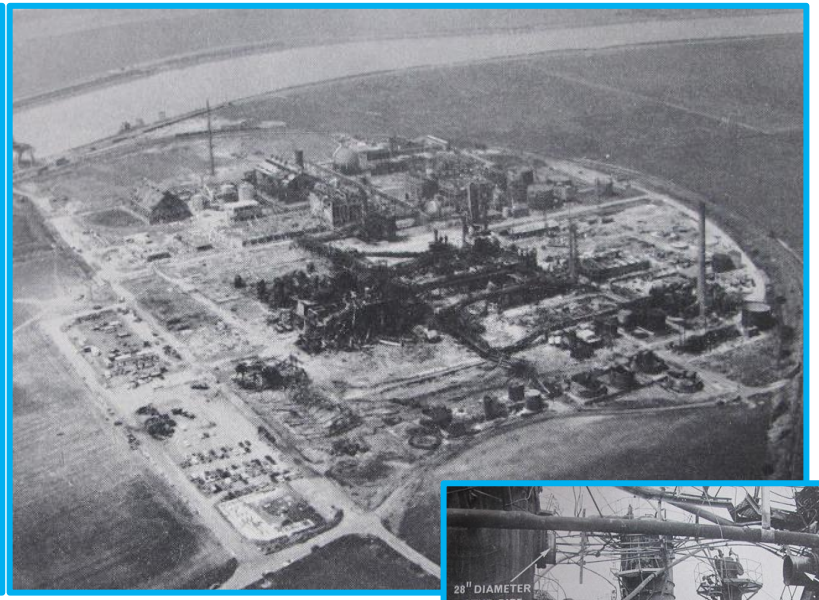


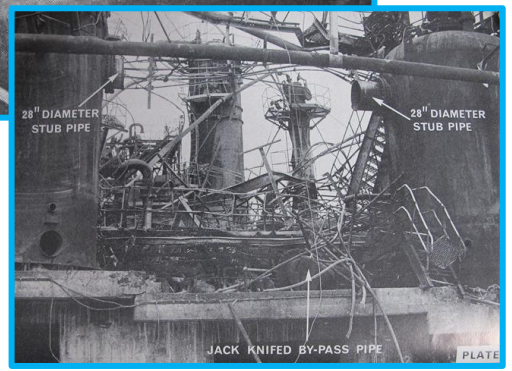
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	* 71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	** 103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

- Liquid Metal Embrittlement (LME)
  - Rapid, brittle failure of a ‘ductile’ material exposed to a liquid metal and under stress.
  - Intergranular cracking decorated with the ’active’ metal.
  - Austenitic stainless steels vulnerable to Zinc LME, ferritic steels also?

Nypro Chemical Works, Flixborough (UK), 1st June 1974







- A local fire caused melting of Zinc galvanizing on steel components above a T316L stainless steel pipe connecting two reactors and carrying cyclohexane.
- Investigation established the stainless steel pipework to have failed by Liquid Metal Embrittlement.

Incident killed 28 and injured another 36 from a weekend workforce of 72.

Further Examples

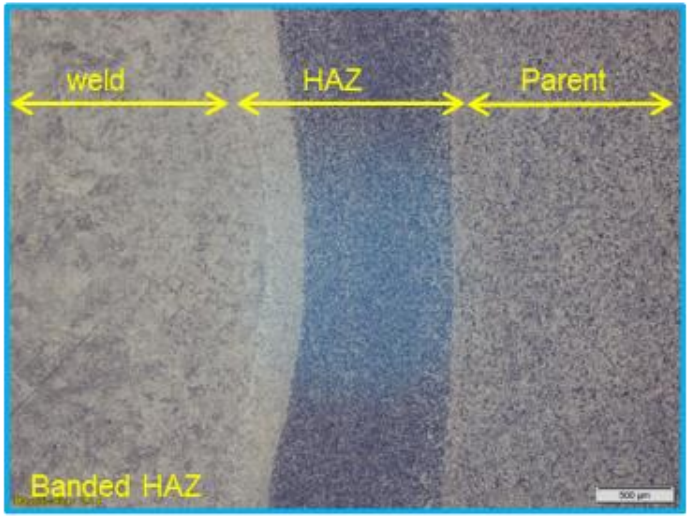
- During construction of an unnamed chemical plant, Type 304 and Type 316L stainless steel piping was erected and then welded on site to structural steelwork painted with Zinc-rich primer. The piping was then welded.
- Multiple leaks detected during hydrotesting with subsequent NDE revealing numerous cracks in the weld HAZs.
- Laboratory investigation confirmed the presence of Zinc in intergranular cracks adjacent to the weld passes.
- Attributed to LME, the cracking coincided with positions where the pipe surfaces were coated with localized splatters of the brushed/sprayed-on Zinc-rich primer.

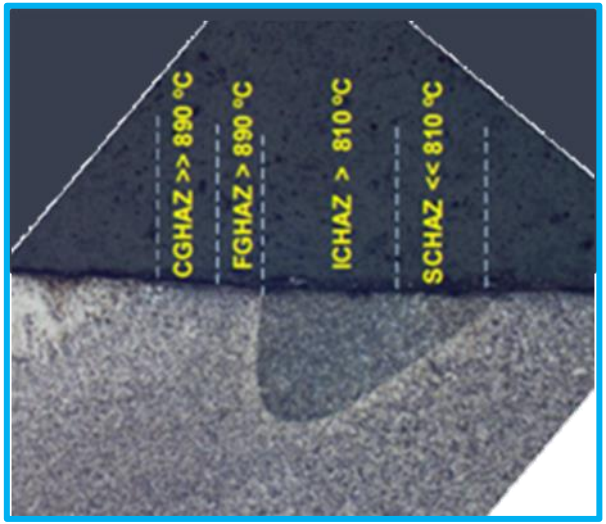
- During a pre-service hydraulic test, stainless steel tanks exhibited leaks at almost every position where galvanized steel access ladders had been directly welded onto the tank walls.
- LME by Zinc was again implicated.

- Considered Good Practice requires the removal of a galvanized coating prior to welding (may not always be completely effective).

Effect of Zinc Paint on HRSG P91 Components

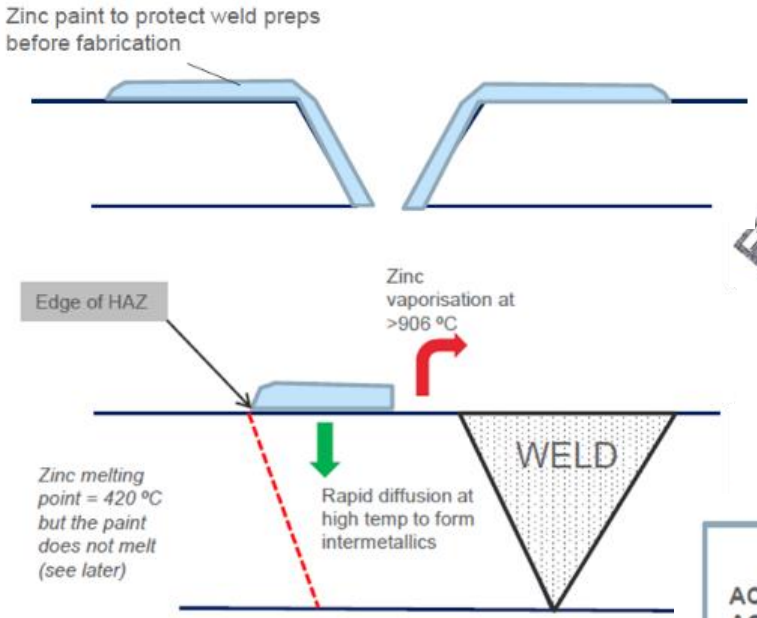
- Further investigation found dark bands in the HAZs of numerous surface replicas obtained from various P91 components, with high levels of voids apparent in the dark bands.
- Presence of Zinc potentially making the material more creep susceptible.
- Following examination of boat samples, the banding was again confirmed to be a localised region of Zinc-affected material. Intermetallic Zinc, not LME!
- There were various theories as to the cause of this banding (e.g. heat treatment), but it appeared to be a largely a surface effect.

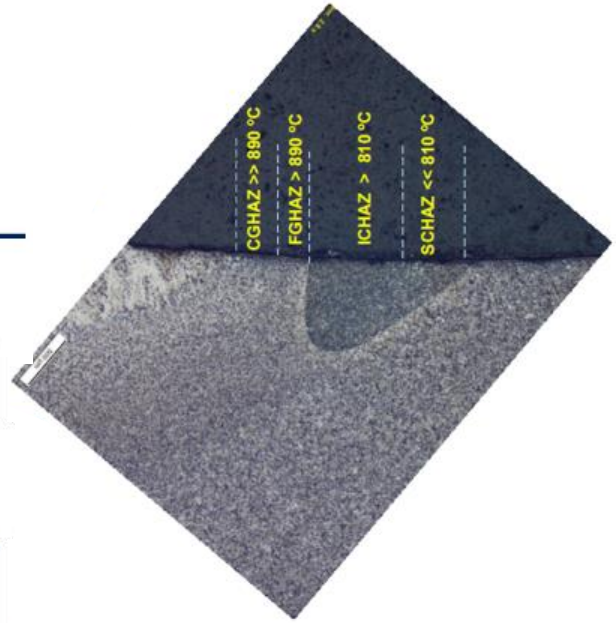




Effect of Zinc Paint on HRSG P91 Components

How did Zinc get into the HAZs?





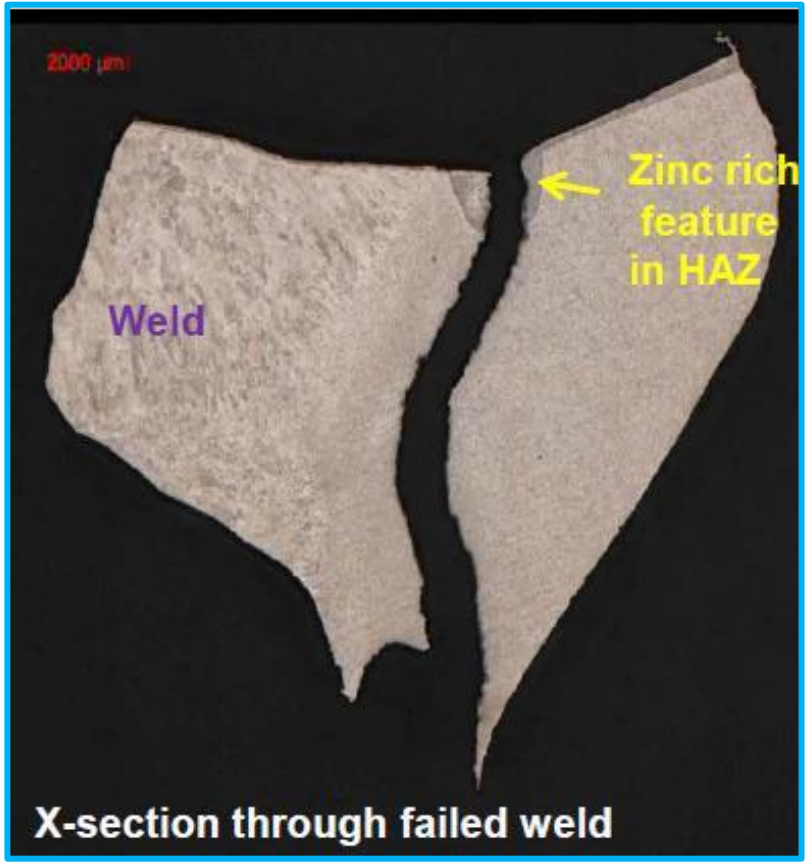
AC3 for P91 = 890 – 940 °C
AC1 for P91 = 810 °C

CG HAZ >> AC3
FGHAZ > AC3
AC3>ICHAZ>AC1
SCHAZ<AC1

Effect of Zinc Paint on HRSG P91 Components

- For Uniper, it has become apparent that careful analysis of surface replicas is required to determine the “true” extent of creep cavitation when assessing P91 components that have a Zinc-based coating.

- In Europe, there has been an example of the localized coating associated with Zinc paint potentially acting as a “metallurgical notch” possibly prompting crack initiation.



Uniper Approach

- The current ‘Procurement Specification’ explicitly prohibits the use of elemental paints (may require QA checks).
- Freshly applied ethyl-silicate-based elemental Zinc paint exhibits a smooth, beige-yellow appearance, but becomes darker with exposure to elevated temperatures.
  - Can be similar in appearance to grey Zinc phosphate paints and primers – these contain Zinc as a compound and are regarded as LME inert.
  - Readily distinguishable from the ‘red lead’ (Pb_3O_4 based) coating traditionally used.
- Where elemental Zinc suspected in coating, or uncertainty exists, analysis of a scrapping is performed.
- Integrity concerns are confined to weld HAZs where depth of Zinc penetration is significantly greater than remote from a weld.
- Any remedial work on Zinc coated systems requires grinding back to bright metal a good distance (>50mm) from the weld preparation.
- Where replication identifies a dark band of creep weak material consider grinding out to clear banding and monitor at future inspections.

SUMMARY

- The surface replication of high temperature components fabricated in Grade 91 in UK CCGT plant has revealed a dark etching band adjacent to welds.
- The dark band is relatively shallow, confined to the weld HAZ and, with extended service, is often associated with creep cavitation.
    - Zinc infiltration occurs during welding rather than in-service.
- On site and laboratory analysis has confirmed the dark band in the HAZ to be due to Zinc infiltration associated with the use of Zinc-based weldable paint primers (ethyl-silicate-based elemental Zinc paint).
    - Intermetallic Zinc, not LME.
    - Not all Zinc coatings are bad!
- Presence of Zinc potentially makes the material more creep susceptible, acting as a “metallurgical notch” and prompting crack initiation.
- Approaches have been developed to address the considered risk of damage.

uniper

Engineering for the Energy Evolution

For detailed information please contact:

Paul James

Senior Materials Engineer

+44 7899 064712

paul.james@uniper.energy

https://engineering.uniper.energy/

linkedin.com/showcase/uniper-engineering

twitter.com/uniper_energy