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MATERIEX CASE STUDY 24-2

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LEAKAGE IN SEAWATER COOLING SYSTEM

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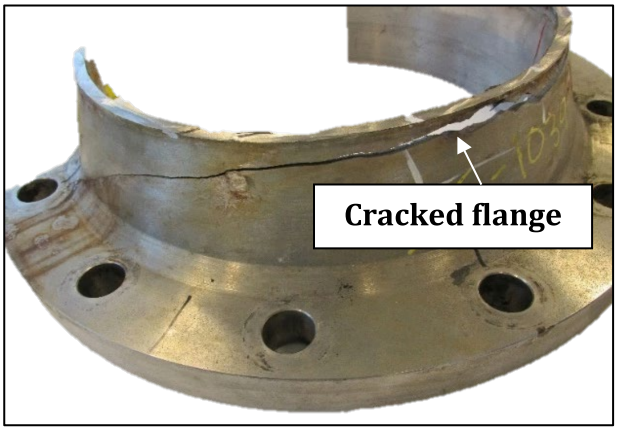
BACKGROUND

Shortly after the commissioning of an offshore HVDC converter station in the North Sea, leakage was discovered in the seawater cooling system. The cooling system consisted of pipes and flanges that had been joined by welding. According to materials certificates, the pipes, flanges, and welds should meet the criteria for super duplex stainless steel conforming with EN 1.4410.



INVESTIGATION

The investigation included the following:

- On-site inspection
- Visual inspection of collected samples
- Fractography of cracked flanges using SEM
- Verification of the chemical composition using XRF
- Hardness measurements using a micro-Vickers hardness indenter
- Verification of microstructure and secondary phases using LOM and EBSD

SEM - Scanning electron microscopy
XRF - X-ray fluorescence
LOM - Light optical microscopy
EBSD - Electron backscatter diffraction

FINDINGS

- Cracks and defects (Figure 1) were observed in several flanges whereas the pipes and welds appeared to be in a good condition.
- A detailed study using SEM showed that the cracked flange had the character of a typical brittle cleavage mode of fracture (Figure 2).
- EBSD phase mapping of the microstructure unambiguously confirmed the presence of sigma phase in all investigated flange samples (Figure 3a) whereas the pipes and welds had an expected microstructure free from sigma phase and with a homogenous distribution of ferrite and austenite (Figure 3b-c).
- The hardness was higher than specified in areas rich in sigma phase (>10 wt.-%), as shown in Table 1. However, the pipe hardness was lower and did meet requirements according to the materials specifications.
- The chemical composition of all analysed pipes and flanges conformed with the specified super duplex stainless steel (Table 2).

CONCLUSIONS

The flange material had suffered from what in the literature is known as Sigma phase embrittlement that had dramatically reduced the corrosion resistance and ductility of the flange material. Exposure to seawater had subsequently accelerated local corrosion and promoted cracking. Sigma phase is an undesired chromium/molybdenum-rich intermetallic phase that can form during incorrect heat treatment of stainless steel. Most likely, too slow cooling through the 700-900 °C temperature range has led to the eutectoid transformation of ferrite into sigma phase and secondary austenite.

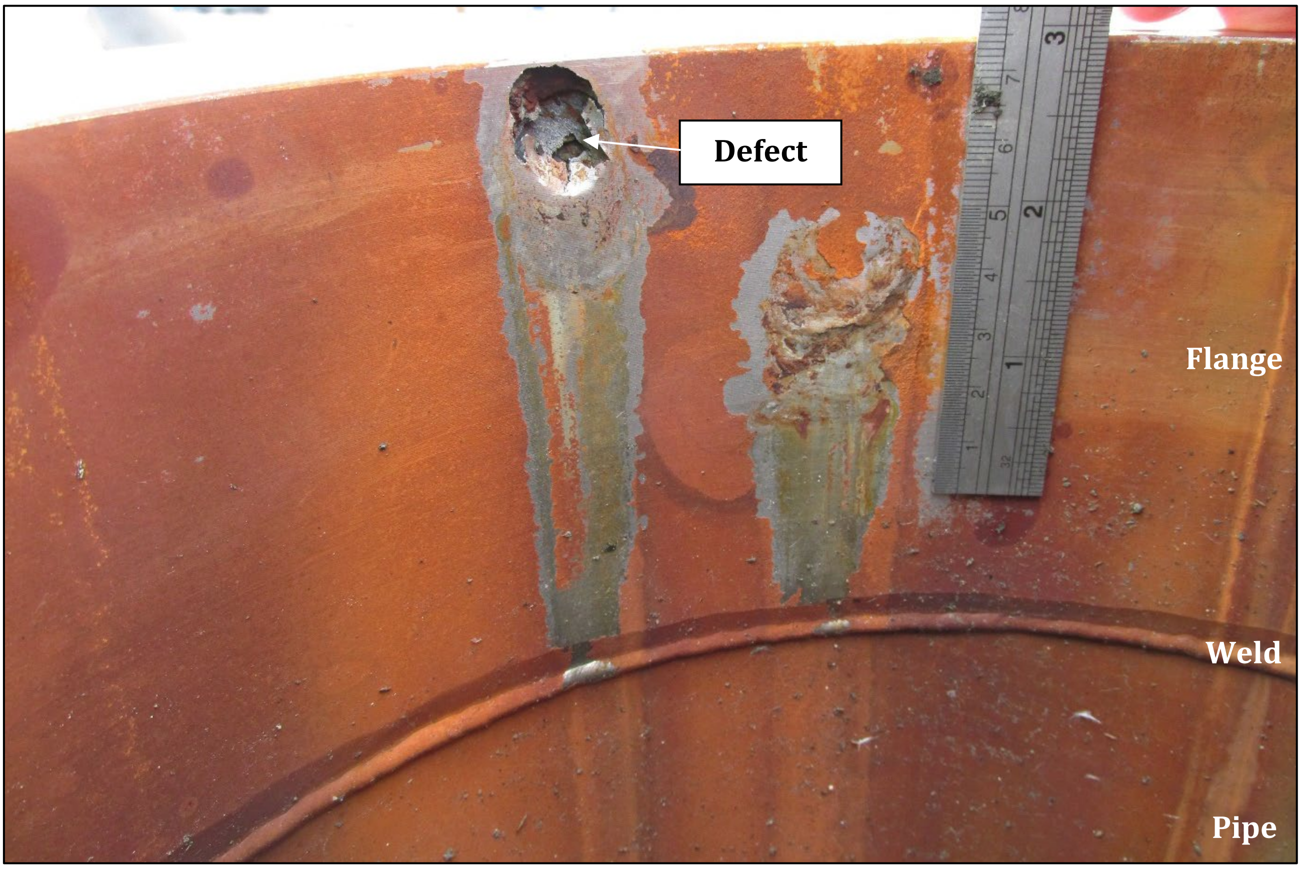


Figure 1. *Flange defect observed during on-site inspection.*

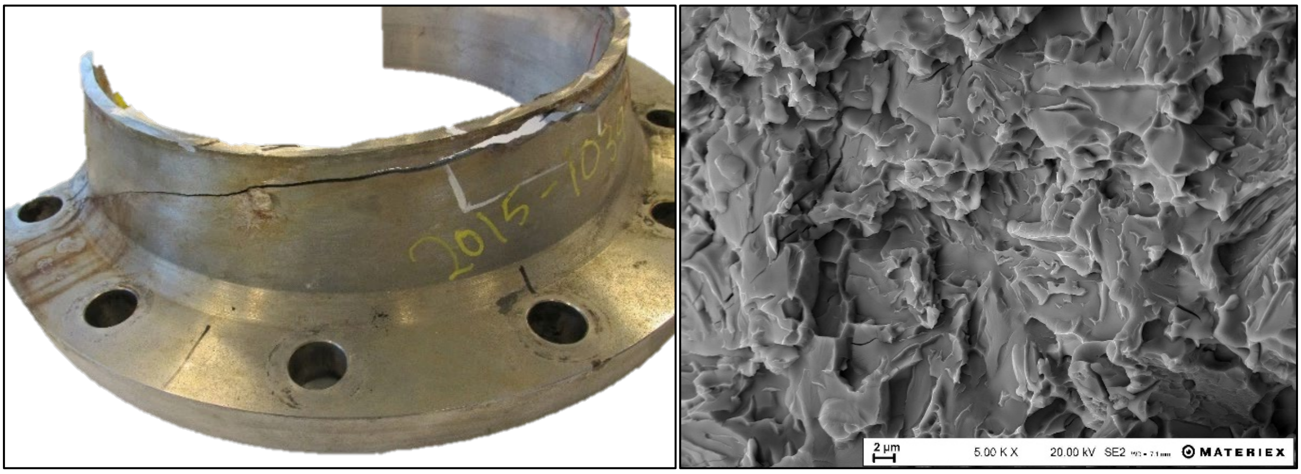


Figure 2. *Left: cracked flange. Right: SEM-image of fracture surface showing a brittle cleavage mode of fracture.*

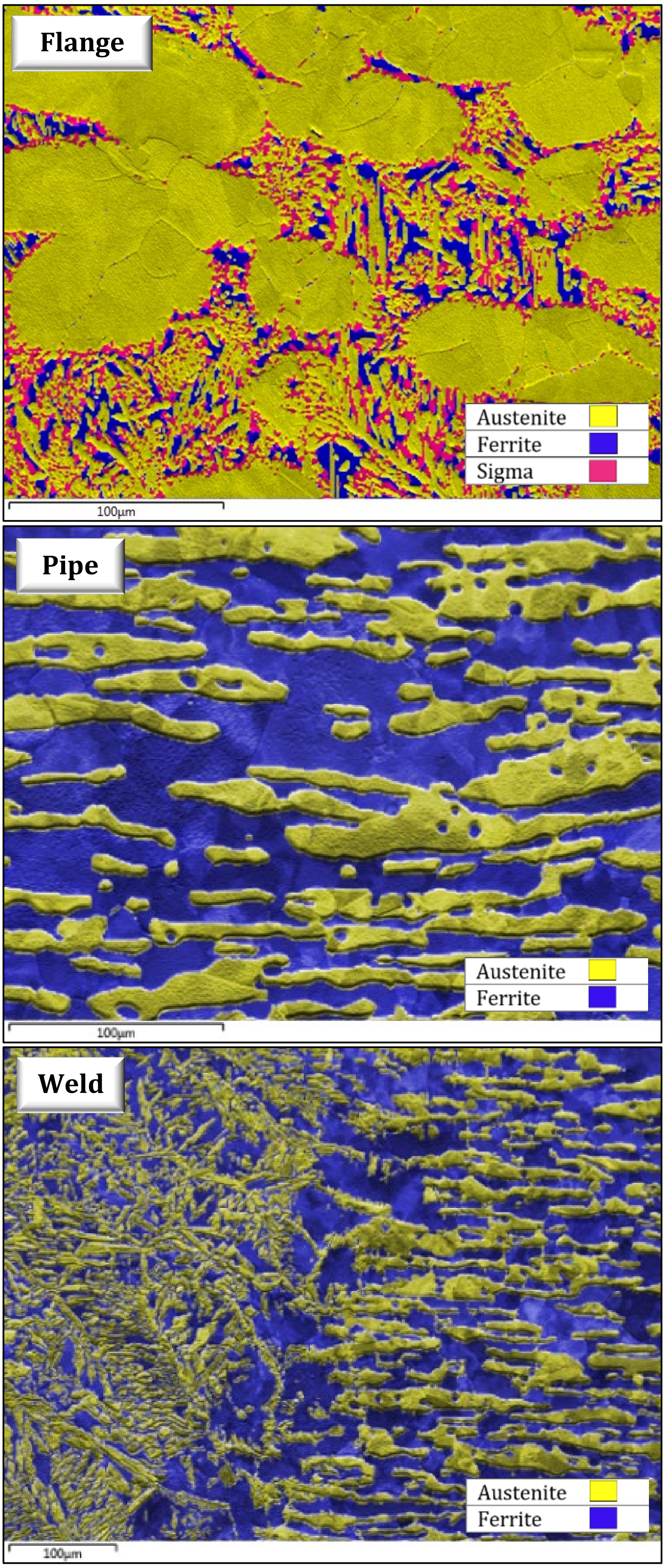


Figure 3. *EBSD phase mapping revealing the presence of Sigma phase in flange material. The pipes and welds were free from sigma phase and had an expected microstructure of austenite and ferrite.*

Table 1. *Hardness measurements and phase identification.*

Position	Hardness [HV_{10}]	Austenite [%]	Ferrite [%]	Sigma [%]
Pipe	248 (~235 HB)	56	44	-
Flange	**369 (~350 HB)**	79	5	**16**
Specified	*≤ 310 HB*	*45–75*	*35–55*	

Table 2. *Chemical composition of different parts [wt.-%].*

Type	Cr	V	Mn	Fe	Ni	Cu	Zn	Mo	W
Flange	24.3	0.2	1	64.2	6.4	0.4	0	3.4	-
Weld	24.4	0.1	0.8	61.2	7.8	0.5	0.1	3.5	0.3
Pipe	24.0	0.1	0.9	63.8	6.7	0.4	0	3.4	-
Specified	*24–26*		*≤ 1.2*	*Bal*	*6–8*			*3–5*	

Table 3. *Summary of chemical composition versus microstructure.*

Position	Chemical composition OK?	Microstructure
Flange	Yes, as specified	**Ferrite, sigma and austenite.**
Weld	Yes, as specified	Normal weld structure of ferrite/austenite.
Pipe	Yes, as specified	Normal ferrite/austenite.