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RESEARCH ARTICLE OPENACCESS

Critical Properties considerations of metallurgy for Oil and Gas Industries

Ravi Kiran Dasari
Process Engineering Manager, Audubon Companies, Houston, TX, USA

ABSTRACT
The article covers the critical properties of metallurgy to be used in oil and gas industry mainly. Also the different terminology impact is described in detail so that corrosion impact is reduced for the various equipment in the industry. The process conditions are also mentioned as they play a vital role as well under the material of construction.

Keywords–metallic, steel making, heat treatment, non-destructive examination**,** erosion

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I. INTRODUCTION

Metallurgy is the essential part of various sectors and the properties like strength of materials, temperatures and pressures process and design conditions. Design specifications are described and relevant standards are also indicated. Various Terminologies are also indicated to various types of metallurgy applicable to specifically oil and gas industry.

II. METALLURGY PROPERTIES

General Metallurgy

- Nature of metallic materials
  – Crystalline structure
  – Alloys
- Solid solution type
- Precipitation hardening type
- Mechanical alloys
  – Transformation (liquid / liquid and solid / solid)
  – Grains and grain boundaries

Properties of metallic materials

- Physical
  – Thermal coefficient of expansion
  – Thermal conductivity
  – Specific melting point
  – Electrical conductivity / resistivity
  – Specific gravity

Mechanical properties of metallic materials

- Tensile strength at ambient / operating temperatures
- Ductility parameters
- Impact properties (CharpyVee Notch)
- K_1C (stress intensity)
- Fatigue strength (mechanical)
- Thermal fatigue (thermal cycling)
- Creep and Stress rupture properties (high temp. strength)
- Wear and erosion resistance

III. MATERIALS OF CONSTRUCTION

- Ferrous
  – C.S, C-Mn, C-1/2 Mo, Cr-Mo, Ni steels, stainless steels, cast irons etc
- Non-ferrous metallic materials
  – Copper alloys, brass, Al alloys, Ti alloys, Ni based alloys, Cobalt based alloys etc
- Ceramics
  – Mostly carbides, oxides, nitrides borides etc.
- Refractories
  – Mechanical mixtures, shapes, monoliths, ceramic fiber, castables, ceramic cloth
- Plastics including elastomers
- Ceramics
- Generally very hard and brittle
- Very high temperature applications
- Refractories
- Bricks are used in heaters and some reactors
- Ceramic fiber is commonly used for cold wall equipment in a high temperature application (expansion joints & heaters)
- Monoliths / castables are used for insulation (FCCU)
- Plastics
- Low temperature applications for combating aqueous corrosion

System of Materials Designation

- AISI (American Iron & Steel Institute)

- UNS (Unified numbering system)
- Werkstoff (German) (1.4718)
- EN (Euro Norm)
- JIS (Japanese)
- GOST (Russian)
- Others

Product Specifications

- The requirements of a specific product like a plate, forging, pipe or casting etc are specified by the appropriate specification like
- ASME e.g. (SA516-70)
- ASTM e.g. (A516-70)
- AFNOR
- DIN

Codes and Standards

- ASME (It is a construction Code for a pressure boundary. Most of the pressure vessels are built to sec. VIII, div 1 & 2)
- PED (Pressure Equipment Directive of EU. All the pressure vessels now built under the auspices of EU must satisfy PED)
- API (It is not a Code but a standard)
- NACE (Some of the publications are standards and some are recommended practices and some are methods followed by the industry consensus)
- General Industry Practices

Steel Making Terminology

- Deoxidation practice in steel making
- Molten steel contains oxygen and must be removed prior to casting into ingots. The oxygen is removed by adding Al, Si which combines with oxygen to form SiO_2 /Al_2O_3, which floats away as slag. The deoxidized steel is called **"killed Steel"**
- HIC Steels
- This is a term used by the corrosion community which stands for hydrogen induced cracking resistant steels. These steels are extra low S & P steels which are supposed to reduced cracking of carbon steels in sour wet service. General Industry practices does not recommend these steels, because these have not proven to be cost effective and in some cases even detrimental

Fabrication Terminology

- Rolling of plates & sheets
- Forging (open & closed)
- Extrusion (typically for seamless pipes)
- Induction Bending
- Roll Bending
- Spinning (for making large heads for vessels
- Tube expanding (by rolling or high pressure)
- Welding

Heat Treatment Terminology

- **Annealing** (slow cooling from austenitizing temperature)
- **Normalizing** (air cooling from austenitizing temperature)
- **Solution Annealing** (high temp. treatment to dissolve all carbides and make the matrix uniform- used for 304 SS)
- **Tempering** (reheating below the lower critical transformation temperature to reduce strength & improve ductility parameters)
- **PWHT / Stress relieving** (reheat below the tempering temp. to reduce residual stresses from welding & fabrication)
- **Stabilize Anneal** (reheating a solution annealed 321/347 SS material to improve corrosion resistance by deliberately precipitating TiC / NbC and keeping Cr in solid solution)
- **Precipitation Hardening** (Reheating to increase strength by deliberately precipitation of intermetallic compounds)

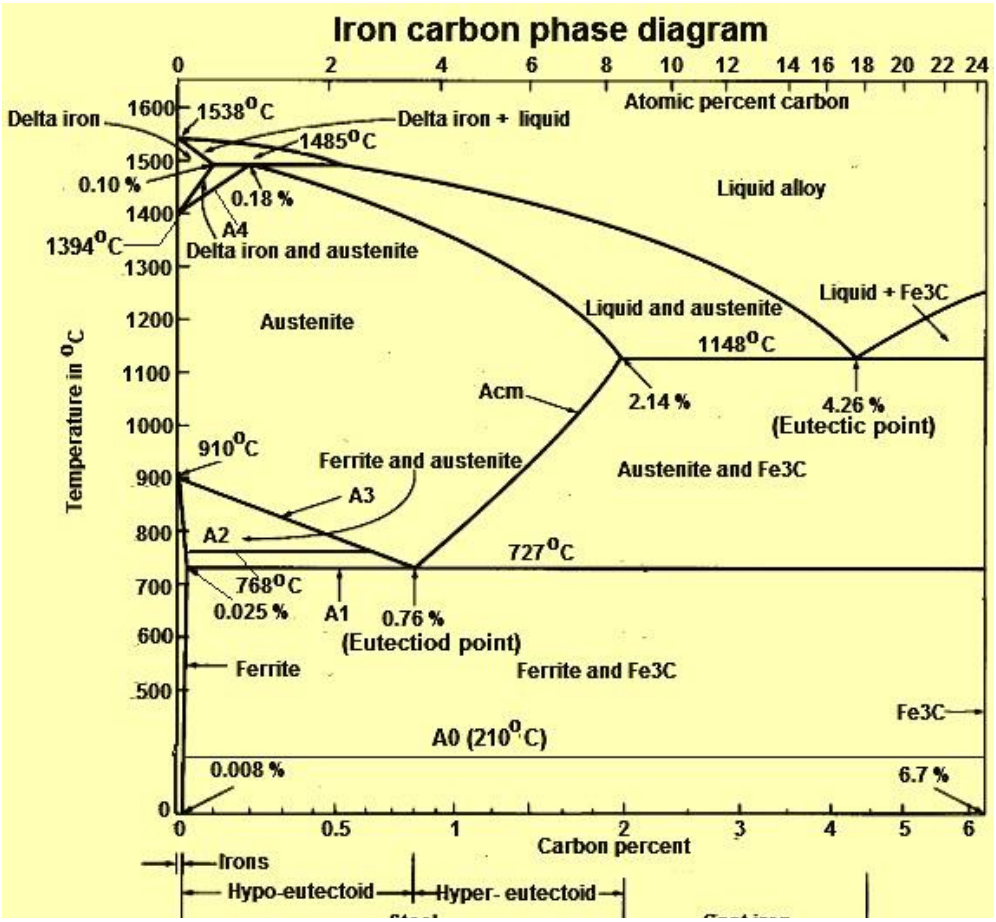

Fig 1: Heat Treatment of Iron and Steel

Non- Destructive Examination

- (PT) Liquid (or dye) penetrant examination
- (MT) Mag. Particle examination (dry /wet)
- (UT) Ultrasonic
- (RT) Radiography X-ray, gamma ray
- Eddy Current
- Acoustic Emission
- Hardness (semi non-destructive)

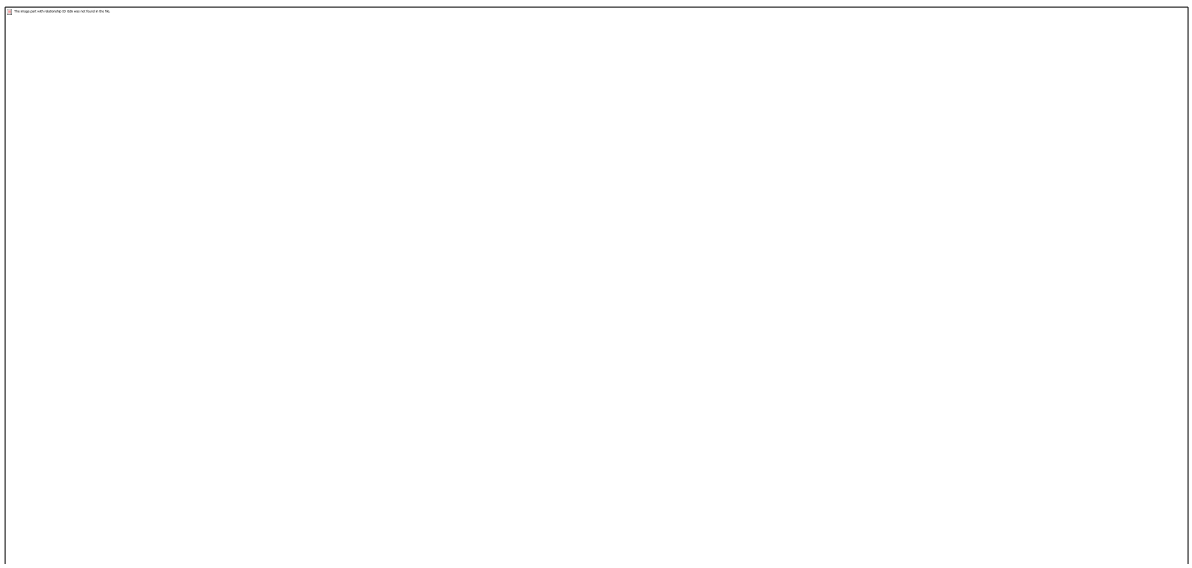

Fig 2: Non-Destructive Testing and Evaluation

- Low Temperature / Brittle fracture

– Brittle fracture is catastrophic & is caused by low temperature properties (measured by charpyvee notch). The rules for preventing brittles are covered by ASME para UCS 66 sec. VIII, div 1. (I have issued a technical alert on this subject, attached as a pdf file)

– **Minimum Design Metal Temperature (MDMT)**

- Temper Embrittlement

– This is common in low alloy steels and occurs when exposed in the range of 800^0 to 1000^0F. This is mitigated by using low tramp elements (P, Sb, Sn) in these steels. These steels are used for hydroprocessing reactors.

- Hydrogen damage at high temperature
- Sigma Phase formation

– Several SS when exposed in the temp. range of 800^o / 1400^oF. It is accompanied by loss of ductility & over a long periods of time leads to failure of the equipment / piping

IV. CORROSION STARTEGIES

- General corrosion (uniform metal loss)
- Galvanic or two-metal corrosion
- Crevice (localized) corrosion
- Pitting (localized) corrosion
- Stress corrosion
- Intergranular corrosion
- Selective leaching
- Erosion corrosion
- High temperature corrosion

– Oxidation

– Carburization

– Metal Dusting (sometimes called catastrophic carburization)

– Graphitization (for Carbon Steels)

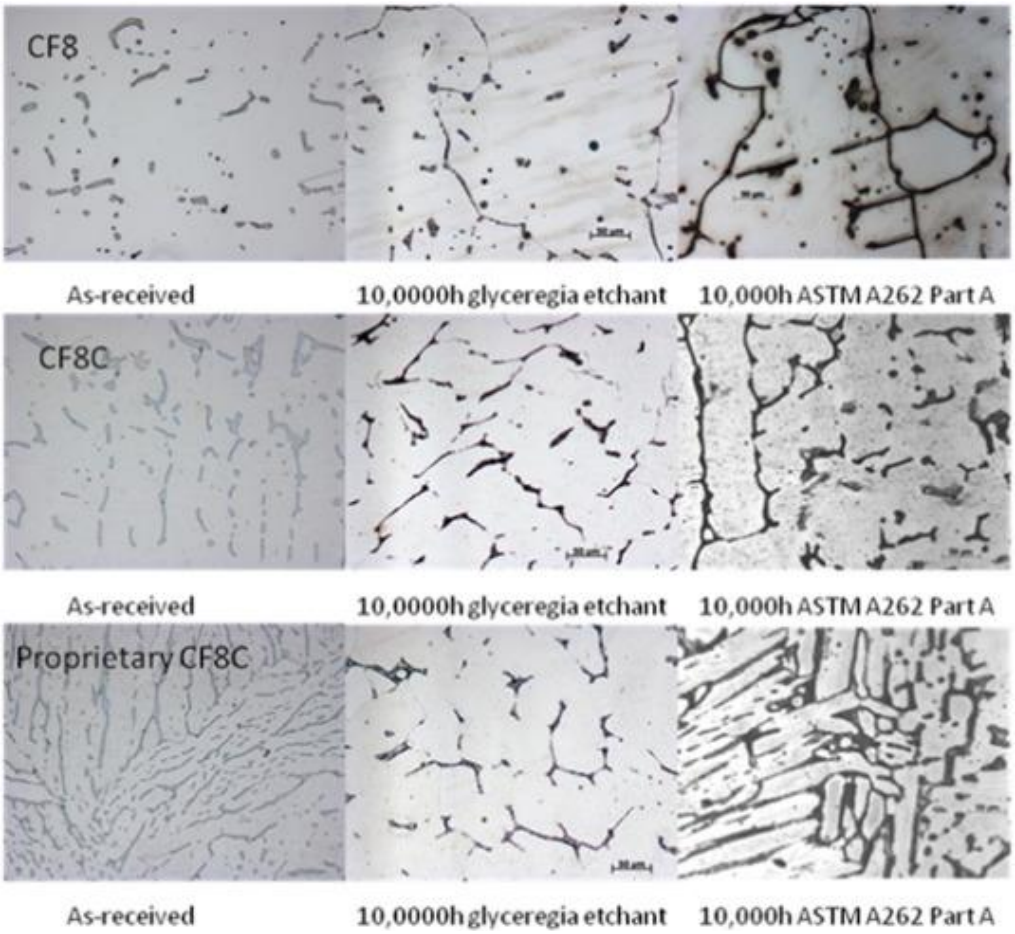

Fig 3: Polythionic Acid Stress Corrosion Cracking (PASCC)

- Polythionic Acid Stress Corrosion Cracking (PASCC)
- Form of stress corrosion cracking when stainless steel is exposed to air, S compounds & moisture & occurs mostly during shut down and start. (NACE RP0170)
- Wet Sour Service (NACE MR0103)
- > 50 ppmw dissolved in free water

- Free water pH <4 & some dissolved H_2S present
- Free water pH >7.6 & 20ppmw dissolved HCN in water and some H_2S present
- >0.0003 MPa (0.05psia) partial press. H_2S in the gas

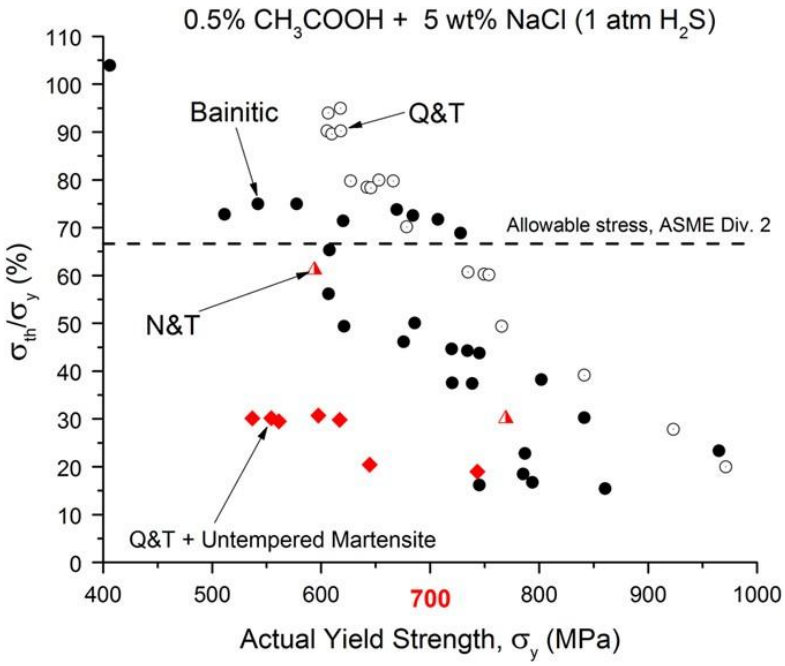

Fig 4: Corrosion and Material trends

V. CONCLUSION

It's always critical to consider the properties of material especially for metals as they eventually corrode and reactive to certain services. Design and process conditions need to be evaluated and also lessons learned from the past projects need to be considered so that the equipment or pipe material can last longer and operate considering safety with regular maintenance

REFERENCES

[1]. Anderko, A., Cao, L., Gui, F., Sridhar, N. &Engelhardt, G. Modeling localized corrosion of corrosion-resistant alloys in oil and gas production environments: II. corrosion potential. Corrosion (2016).

[2]. Anderko, A., Gui, F., Cao, L., Sridhar, N. &Engelhardt, G. R. Modeling localized corrosion of corrosion-resistant alloys in oil and gas production environments: part i. repassivation potential. Corrosion 71, 1197–1212 (2015).

[3]. Siegmund, G., Schmitt, G. &Kuhl, L., Unexpected Sour Cracking Resistance of Duplex and Superduplex Steels. in CORROSION, 7631, 6–10 (NACE International, 2016).

[4]. Yao, J., Dong, C., Man, C., Xiao, K. & Li, X. The electrochemical behavior and characteristic of passive film on 2205 duplex stainless steel under various hydrogen charging conditions. Corrosion **72**, 42–50 (2016).

[5]. Guo, L. Q. et al. Effect of hydrogen on pitting susceptibility of 2507 duplex stainless steel. Corros. Sci. **70**, 140–144 (2013).

[6]. Montagne, A., Audurier, V. &Tromas, C. Influence of pre-existing dislocations on the pop-in phenomenon during nanoindentation in MgO. Acta Mater. **61**, 4778–4786 (2013).

[7]. U.S. Bureau of Labor Statistics. Employer-reported workplace injuries and illnesses–2015. Report No. USDL-16-2056, (Washington, D.C., 2016).

[8]. U.S. Chemical Safety and Hazard Investigation Board. Investigation report volume 2-Explosion and fire at the Macondo well. Report No. 2010-10-I-OS, (Washington, D.C., 2014).

[9]. Bell, J. M., Chin, Y. D. & Hanrahan, S., State-of-the-Art of Ultra Deepwater Production Technologies. in Offshore

Technology Conference, 2–5 (Society of Petroleum Engineers, 2005).
[10]. Iannuzzi, M. in Stress Corrosion Cracking. Theory and Practice (eds Raja, V. S. & Shoji, T.) Ch. 15, 570–607 (Woodhead Publishing, 2011)
[11]. Michie, D. Economic Report 2016 (Oil & Gas, London, U.K., 2016).
[12]. Skeels, H. B. API 17TR8-HPHT Design Guideline for Subsea Equipment. in Offshore Technology Conference, OTC-25376-MS (Houston, TX, Offshore Technology Conference, 2014).
[13]. API 17TR8, High-pressure High-temperature Design Guidelines (American Petroleum Institute, 2015).
[14]. Kfoury, M. Kristin HPHT Gas Condensate Field: challenges, remedial actions & strategy to improve hydrocarbon reserve (Statoil AS, 2012).
[15]. Lehr, D. J. & Collins, S. D., The HPHT Completion Landscape-Yesterday, Today, and Tomorrow. in SPE Annual Technical Conference and Exhibition, SPE-170919-MS, 27–29 (Society of Petroleum Engineers, 2014).
[16]. NACE International Work Group T-1F-21G. Use of Corrosion-Resistant Alloys in Oilfield Environments. Report No. 1F192, (NACE International 2000).
[17]. European Federation of Corrosion. Guidelines on Materials Requirements for Carbon and Low Alloy Steels for H_2S-Containing Environments in Oil and Gas Production. 3rd edn., Vol. Publication No. 16 (Maney Publishing, 2009).
[18]. Smith, L. & Craig, B. D., Practical corrosion control measures for elemental sulfur containing environments. in CORROSION 3–7 (NACE International, 2005).
[19]. Walton, D., Equipment and material selection to cope with high pressure/high temperature surface conditions. in Offshore Technology Conference, OTC-12122-MS (Offshore Technology Conference, 2000).
[20]. Horn, A. M., Østby, E., Hauge, M. & Aubert, J.-M. in The Twenty-second International Offshore and Polar Engineering Conference 290–296 (International Society of Offshore and Polar Engineers, 2012).
[21]. Thaulow, C., Ødegård, J. &Østby, E., Arctic steels criteria for safe materials utilisation. in High Technologies in Advanced Metal Science and Engineering (St. Petersburg, Russia, 2006).
[22]. Alvaro, A., Akselsen, O. M., Ren, X. & Kane, A. in Proceedings of the Twenty-fourth International Ocean and Polar Engineering Conference 247–254 (International Society of Offshore and Polar Engineers, 2014).
[23]. Gangloff, R. P. in Comprehensive Structural Inteqrity Vol. 6 (eds Milne, I., Ritchie, R. O. &Karihaloo, B) Ch. 6.02, 31–101 (Elsevier Science, 2003).
[24]. Miyasaka, A., Denpo, K. & Ogawa, H. Environmental aspects of SCC of high alloys in sour environments. Corrosion **45**, 771–780 (1989).
[25]. Tsujikawa, S. et al. Alternative for evaluating sour gas resistance of low-alloy steels and corrosion-resistant alloys. Corrosion **49**, 409–419 (1993).
[26]. Cao, L., Anderko, A., Gui, F. & Sridhar, N. Localized corrosion of corrosion resistant alloys in H2S-containing environments. Corrosion **72**, 636–654 (2016).
[27]. Sekido, K., Ohmura, T., Hara, T. &Tsuzaki, K. Effect of Dislocation Density on the Initiation of Plastic Deformation on Fe–C Steels. Mater. Trans. **53**, 907–912 (2012).