Critical aspects of materials for Refinery & Fertilizer Plants

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IIChE-FAI Programme
on
Materials of Construction for Chemical Process Plants

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Materials for Process plants

The art of material selection lies in designing an economic system with maximum reliability in operation and ease of maintenance

Points for discussions

- Selection & ordering Materials
- Precautions in repair/ maintenance

CRITICAL FACTORS IN MATERIALS & DESIGN

Service Environment & Operating Conditions

- Corrosive Environment eg : Urea
- Hydrogen, H_2S (Sour)
- Levels of chloride
- Carburizing env. –Metal dusting
- Temperature (Low, Med, High)

eg : R G Boiler Ferrules - Inconel or Ceramic

Urea Stripper Tube - Bimetallic tubes, Safurex, DP 28W

Ammonia Converter & Reactors – Cr-Mo steels

Material properties

- Strength at Design Temperature
  - Yield Strength
  - Ultimate Tensile Strength
  - Creep Rupture Strength
- Notch Toughness (Impact test)
- Effect of Manufacturing Cycle

Material properties

- Manufacturability
  - Weldability
  - Ductility, Formability
  - Machinability
- Ease of repair
- Availability & Cost

Materials for Process Plants: Guidelines

- **Selection of materials by considering**
  - H_2 gas service
  - Metal dusting aspects in R.G.Boiler
  - Nitriding environment in Synthesis Loop Boiler design
  - Effect of chloides at high temperature
- **Impact testing – Temp, min value**
- **Step Cooling requirement for 1.25 Cr-0.5 Mo, 2.5 Cr-1Mo & 3Cr Materials for H_2 embrittlement during material procurement.**
- **Corrosion testing of material during procurement**
- **Effect Of Manufacturing Cycle - Simulation Heat Treatment**

High Temperature Hydrogen Attack (HTHA)

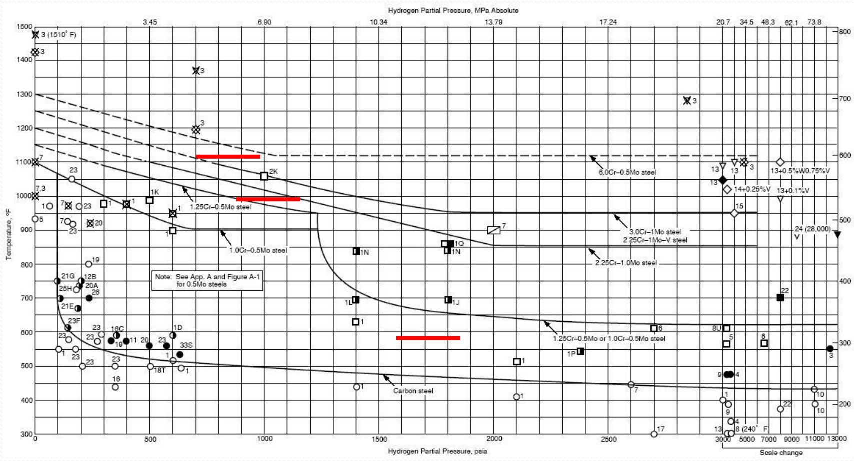
- Description of Damage
  - The hydrogen reacts with carbides in steel to form methane (CH_4) which cannot diffuse through the steel. The loss of carbide causes an overall loss in strength
  - Methane pressure builds up, forming bubbles or cavities, microfissures and fissures that may combine to form cracks
  - Failure can occur when the cracks reduce the load carrying ability of the pressure containing part

High Temperature Hydrogen Attack (HTHA)

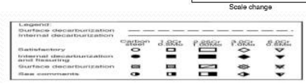
- Affected Materials
  - C-0.5Mo, Mn-0.5Mo, 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, 2.25Cr-1Mo-V, 3Cr-1Mo, 5Cr-0.5Mo and similar steels
- Critical Factors
  - For a specific material, HTHA is dependent on temperature, hydrogen partial pressure, time and stress
  - HTHA occurs over a period of time when no noticeable change in properties is detectable by normal inspection techniques.
  - Nelson Chart contains curves that show a temperature/hydrogen partial pressure safe operating envelope for carbon and low alloy steels
  - The curves are reasonably conservative for carbon steel up to about 10,000 psi hydrogen partial pressure

Nelson Chart : Material Selection chart for Hydrogen service

- Does not account for other corrosive s in the stream
- Does not account for creep or other damage mechanism
- Limits described in this curve is based on service experience

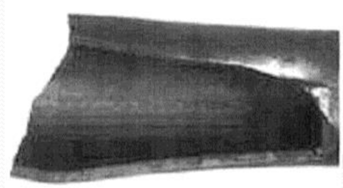


LEGEND



High Temperature Hydrogen Attack (HTHA)

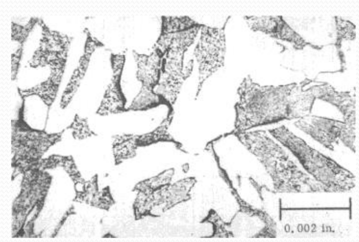
- Affected Units
  - Hydroprocessing units, such as hydrotreaters (desulfurizers) and hydrocrackers, catalytic reformers, hydrogen producing units and hydrogen cleanup units, such as pressure swing absorption units
  - Boiler tubes in very high pressure steam service



- **Figure 5-36 - Brittle appearing failure of a pipe section due to HTHA**

Precaution during manufacturing :

HTHA is material & service dependen phenomena.
No specific precautions needs to be taken, However, Suitable DHT procedure shall be devised during repair & maintenance



photomicrograph showing microfissuring (high MF)

High Temperature Hydrogen Attack (HTHA)

- Inspection and Monitoring
  - Damage may occur randomly in welds or weld heat affected zones as well as the base metal, making monitoring and detection of HTHA in susceptible materials extremely difficult
  - Ultrasonic techniques using a combination of velocity ratio and backscatter have been the most successful in finding fissuring and/or serious cracking
  - In-situ metallography can only detect microfissuring, fissuring and decarburization near the surface
  - Visual inspection for blisters on the inside surface may indicate methane formation and potential HTHA(but HTHA may frequently occur without the formation of surface blisters)
  - Other conventional forms of inspection, (WFMT and RT) are severely limited in their ability to detect anything except the advanced stages of damage where cracking has already developed
  - AET is not a proven method for the detection of damage

High Temperature Hydrogen Attack (HTHA)

- Prevention/Mitigation
  - Use alloy steels with chromium and molybdenum to increase carbide stability thereby minimizing methane formation. Other carbide stabilizing elements include tungsten and vanadium.
  - C-0.5Mo material are not stable under HTHA conditions due to the different carbides formed during the various heat treatments applied to the fabricated equipment.
  - As a result of the problems with the 0.5 Mo alloy steels, its curve has been removed from the main set of curves and the material is not recommended for new construction in hot hydrogen services
  - 300 Series SS overlay and/or roll bond clad material is used in hydrogen service where the base metal does not have adequate sulfidation resistance. Although it is recognized that properly metallurgically bonded austenitic overlay/clad will decrease the hydrogen partial pressure seen by the underlying metal

Impact Requirements & testing

- Factors to be considered for low temperature service materials:
  - Fracture toughness / ductility
  - Stress concentration effect
- Decrease in temperature increases the yield and tensile strength.
- Temperature range at which material changes gradually from ductile to brittle is called transition temperature.
- Above transition temperature, material behaves in a predominantly ductile manner and below transition temperature material behaves in a predominantly brittle.
- Ductility/fracture toughness is measured by Charpy V-notch impact test at minimum design temperature for base material , weld & HAZ
- Test results shall meet the criteria given in design code.

Impact Requirements & testing

Impact Testing:

- METHODS : CHARPY / IZOD
- METHOD USED AT : ASTM Calibrated Charpy Impact Testing
- TEST TEMPERATURES : +100 °C to -196 °C
- IMPACT SPECIMEN SIZ : 10 x 10 x 55 mm along with 2 mm Notch
- TEST ACCEPTANCE : ASME SEC VIII-Div.1 ,Div.2 , SEC II A, SEC IIC

- Generally for CS & LAS materials, Higher the strength-Lesser the toughness
- Higher the PWHT temperature & soak, better will be the toughness values. However, this will lead to reduction in material strength
- AS per API, materials shall be simulated and tested for minimum PWHT (Impact) and maximum PWHT (strength) condition for three cycles

Temper Embrittlement

- Description of Damage
  - Temper embrittlement is the reduction in toughness due to a metallurgical change that occur in some low alloy steels as a result of long-term exposure in the temperature range about 650° F to 1100° F (343° C to 593° C)
  - This change causes an upward shift in the ductile-to-brittle transition temperature as measured by Charpy impact testing
  - This phenomenon is related to to the concentration of low-melting point elements (P, Sb, Sn, and S) in the grain boundaries, the crack path is intergranular.

- Affected Materials
  - Primarily 2.25Cr-1Mo low alloy steel, 3Cr-1Mo (to a lesser extent), and the high-strength low alloy Cr-Mo-V steels
  - The C-0.5Mo and 1.25Cr-1Mo alloy steels are not significantly affected by temper embrittlement

Temper Embrittlement : Critical Factors

- Alloy steel composition, thermal history, metal temperature and exposure time
- Susceptibility to temper embrittlement is largely determined by the presence of the alloying elements manganese and silicon, and tramp elements phosphorus, tin, antimony and arsenic
- Temper embrittlement of 2.25Cr-1Mo steels develops more quickly at 900° F (482°C) than in the 800°F (440°C)
- Some embrittlement can occur during fabrication heat treatment
- This form of damage will significantly reduce the structural integrity of a component containing a crack-like flaw.

Temper Embrittlement : Affected Units/Equipment

- Temper emrittlement occurs in a variety of process units after long therm exposure to temperatures above 650°F (343°C)
- Equipment susceptible to temper embrittlement is most often found in hydroprocessing units, particularly reactors, hot feet/effluent exchanger components, and hot HP separators.
- Welds in these alloys are often more susceptible than the base metal and should be evaluated.

Typical Step Cooling Cycle

1100 °F (593 °C) /1 hr, followed by furnace cool to
1000 °F (538 °C) /15 hrs, followed by furnace cool to
975 °F (524 °C) /24 hrs, followed by furnace cool to
925 °F (496 °C) /60 hrs, followed by furnace cool to
875 °F (468 °C) /100 hrs, followed by furnace cool to
600 °F (315 °C) /0 hrs, followed by air cool

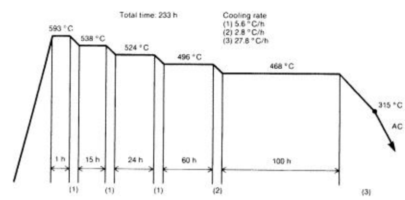


Fig. 7.6. Typical step-cooling cycle for temper-embrittlement studies (Ref 6).

Temper Embrittlement

- Prevention Control in Materials
  - The best way to minimize the like hood and extend of temper embrittlement is to limit the acceptance levels of manganese, silicon, phosphorus, tin, antimony, and arsenic in the base metal
  - A common way to minimize temper embrittlement is to limit the „J*“ factor for base metal and the „X“ factor for weld metal, based on material composition as follows:

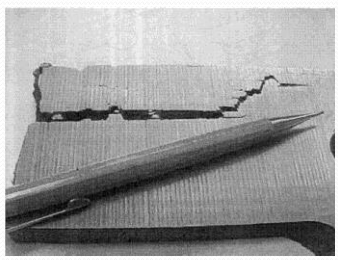
$J^* = (Si + Mn)\times(P + Sn)\times10^4$

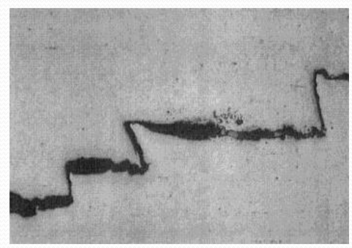
$X = (10P + 5Sb + 4Sn + As)/100$

  - Typical J* and X factors used for 2.25 Cr steel are 100 and 15, respectively
  - Additionally, Cu is 0.20 % maximum, and Ni is 0.30 % maximum (0.25 % maximum for advanced steels).
  - Welding consumables are also procured with these controls

Wet H_2S Damage (Blistering/HIC/SOHIC/SSC)

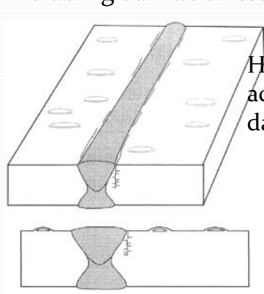
- Description of Damage
  - Hydrogen Induced Cracking (HIC)
    - Hydrogen blisters can form at many different depths from the surface of the steel, in the middle of the plate or near a weld.
    - In some cases, neighboring or adjacent blisters that are at slightly different depths (planes) may develop cracks that link them together.
    - Interconnecting cracks between the blisters often have a stair step appearance, and so HIC is sometimes referred to as "stepwise cracking"



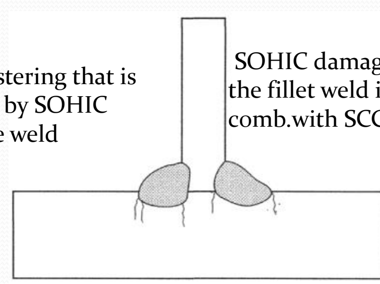


Wet H_2S Damage (Blistering/HIC/SOHIC/SSC)

- Description of Damage
  - Stress Oriented Hydrogen Induced Cracking (SOHIC)
    - SOHIC is similar to HIC but is a potentially more damaging form of cracking which appears as arrays of cracks stacked on top of each other. The result is a through-thickness crack that is perpendicular to the surface and is driven by high levels of stress (residual or applied)
    - Usually appear in the base metal adjacent to the weld heat affected zones where they initiate from HIC damage or other cracks or defects including sulfide stress crack



Hydrogen blistering that is accompanied by SOHIC damage at the weld

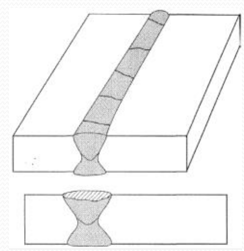


SOHIC damage at the fillet weld in comb.with SCC

Wet H_2S Damage (Blistering/HIC/SOHIC/SSC)

- Description of Damage
  - Sulfide Stress Corrosion Cracking (SSC)
    - Sulfide Stress Cracking (SSC) is defined as cracking of metal under the combined action of tensile stress and corrosion in the presence of water and H_2S
    - SSC resulting from absorption of atomic hydrogen that is produced by the sulfide corrosion process on the metal surface
    - SSC can initiate on the surface in highly localized zones of high hardness in the weld metal and heat affected zones
    - PWHT is beneficial in reducing the hardness and residual stresses that render a steel susceptible to SSC.

- **SSC damage of a hard weld**



Wet H_2S Damage (Blistering/HIC/SOHIC/SSC)

- Affected Materials
  - Carbon steel and low alloy steels
- Critical Factors
  - Environmental conditions (pH, H_2S level, contaminants, temperature)
  - material properties (hardness, microstructure, strength)
  - Tensile stress level (applied or residual)
  - Steel making Process contrl
  - PWHT

Material consideration for HIC-NACE requirement (Carbon Steel)

- Steel shall be manufactured preferably by Basic oxygen or electric furnace process. Steel shall be vacuum degassed.
- The chemical composition of the plates shall be restricted to
- S<=0.001%, P<=0.015%, Ni<=0.3%, V + Nb + Ti<=0.12%

Grade	SA 516-60	SA 516-65	SA 516-70
Carbon	<=0.20%	<=0.20%	<=0.23%
Carbon Equivalent*	<=0.36	<=0.40	<=0.43

*Carbon Equivalent= C+ Mn/6 + (Cr+Mo+V) / 5 + (Ni+Cu) /15

Material consideration for HIC-NACE requirement (Carbon Steel)

- Plates shall be supplied in normalized condition.
- Hardness shall be less than 200BHN
- Impact test to be carried out as per S.5 of SA 516, acceptance as per SA 20 Table A2.15.
- Plates shall be ultrasonically tested to SA 578 or SA 435.
- Plates in thickness 25mm and above shall be tested for through thickness tension test as per SA770 to meet acceptance criteria of reduction of area 35% minimum.
- Steel processing route shall be optimized to ensure minimal microstructure ferrite/ pearlite banding, centre line segregation and inclusions.

Austenitic SS – Material Consideration

What does Intergranular Corrosion mean ?

Intergranular corrosion (IGC) can be defined as an attack along the boundaries of grains of the metal. IGC occurs as a result of precipitation of carbides, nitrides, and other intermetallics phases along the grain boundaries.

Sensitization :

Austenitic stainless steels, Cr is added for corrosion resistance & Cr level is usually 18%. When material is held at temperature range of about 520° to 800°C for some period (in minute), Cr will combine(react) with carbon & chromium carbide is formed. Thus Cr % gets reduced below the threshold limit of 11% & the material can corrode. The mechanism involved is precipitation of chromium carbide at the grain boundaries due to heating at range of temperature range of about 520° to 800°C, resulting in the formation of chromium-depleted zones along grain boundaries. This process is called **sensitization**.

Austenitic SS – Material Consideration

Localized attack at and adjacent to grain boundaries, with relatively little corrosion of the grains. The alloy, sensitive to IGC, disintegrates and/or loses its strength when exposed to environments.

Causes of intergranular corrosion

A. Segregation of impurities at the grain boundary ex) Fe in Al alloys.

B. Enrichment of one of the alloying elements or depletion of one of these elements in the grain boundary areas.

Intergranular Corrosion of stainless steels and nickel based alloys

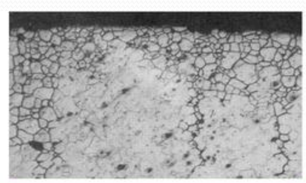
Exposed temperature : 425 °C to 815 °C

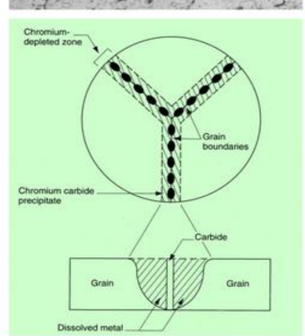
↓

Sensitization

↓

This results from the preferential attack of Cr depleted zone due to precipitation of $Cr_{23}C_6$ at grain boundary.





Austenitic SS – Material Consideration

- Preheater tube failure

Gas pipe line failure

- Photograph showing failure due to intergranular corrosion

Austenitic SS – Material Consideration

How to reduce the risk of IGC ?

Several methods have been suggested to control or minimize IGC of Aust. SSs.

1. ***Controlling Carbon %:*** Use Low-carbon & ELC (extra low carbon) stainless steels materials with less than 0.05% and maximum 0.03% carbon normally have sufficient resistance against IGC.

2. ***Using stabilized Grades***: *Stabilized Grades like SS 321 & 347 have* strong carbide formers or stabilizing elements such as niobium or titanium. Such elements have a much greater affinity for carbon than chromium. Carbide formation with these elements reduces the carbon available in the alloy for formation of chromium carbides.

2. ***Solution Heat Treatment*** : High-temperature solution heat treatment, commonly termed solution-annealing , can redeem the sensitized material. The alloy is heated to a temperature of about 1,040°C and held at that temp. for a specified duration followed by fast cooling. During this process the precipitated chromium carbide breaks to C and Cr. Sudden cooling does not provide sufficient time for the two elements to recombine while it cools through the sensitizing temp. of 450° to 650°C.

Austenitic SS – Material Consideration

What is stress corrosion cracking ?

Stress corrosion cracking is nucleation and propagation of crack through the prone material under the influence of tensile stress.

Stress corrosion cracking is mainly two types : one is intergranular stress corrosion crack (IGSCC) and the other one is Transgranular stress corrosion crack (TGSCC)

In IGSCC, crack propagation is through grain boundary where as in TGSCC it is across grain.

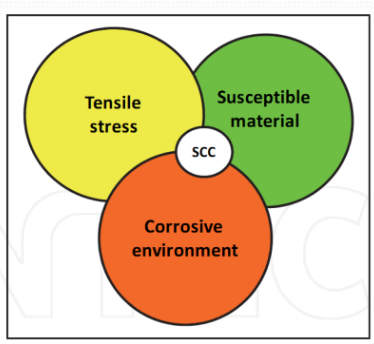
IGSCC

TGSCC

Austenitic SS – Material Consideration

What causes IGSCC ?

IGSCC is due to concurrent existence of three factors.



Conditions necessary for SCC occur.

If one of the above factors is eliminated, IGSCC will not occur.

Corrosion Testing

What is IGC Test? Or How to find the material is sensitized or not?

IGC Test is Intergranular corrosion test. **IGC Test is done to determine whether the material is susceptible to sensitisation or not.** It is also done to know if the material can get sensitized in further processing like welding or any heat treatment etc.

IGC testing is carried out on samples from Aust. SSs finished material or on material that has been given sensitizing heat treatment, i.e. heated in the critical temperature range in a furnace or by welding.

These tests are often run as a qualification test to ensure each batch of stainless steel is properly manufactured.

IGC Test is carried out as per ASTM A 262 Practices.

Corrosion Testing

ASTM A 262 – "Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless steels".

These practices cover the following five tests.

- **Practice A** - *Oxalic Acid Etch Test*
- **Practice B** - *Ferric Sulfate – Sulfuric Acid Test*
- **Practice C** - *Nitric Acid Test*
- **Practice E** - *Copper – Copper Sulfate – 16% Sulfuric Acid Test*
- **Practice F** - *Copper – Copper Sulfate – 50% sulfuric acid Test*

Practice A is a rapid (1 hour) screening test, often used as a first pass to determine the susceptibility to intergranular corrosion. Classification of the structure after Practice A analysis will determine if the material is acceptable or if additional testing is required i.e. "acceptable" or "suspect". **It is not indented to be used for rejecting the material.** If the material is not found acceptable, it must be tested further in the appropriate practices B, C, E and F.

Corrosion Testing

SUMMARY OF PRACTICE B, C, E & F

Practice B, C and F are based on weight loss calculations.
Practice E is based on visual examination of bend specimens.

	Practice - B	Practice – C	Practice - E	Practice - F
Chemical Solution	2.5% Ferric sulfate-50% sulfuric acid	65% Nitric acid	Copper-copper sulfate - 16% sulfuric acid	Copper-copper sulfate-50% sulfuric acid
Duration	120 h	48 h X 3(Min.)	15 h	120 h
Material	304, 304L, 316, 316L, 317, 317L, CF-3,CF-8, CF-3M, CF-8M.	304, 304L, CF-3, CF-8.	201. 202, 301. 304, 304L. 316, 316L, 317, 317L, 321, 347.	CF-3M, CF-8M.
Remarks	48 mpy for 304 SS	18 mpy for 304 SS & 24 mpy for 304L SS	WITHOUT CRACK ACCEPTABLE	40 mpy

Note : ASTM dose not specify acceptance criteria. Hence, Purchaser shall specify the acceptance criteria. The values given in above based on literature survey. A good practice is compare test using unsentisized and suspect specimen. If the corrosion rate is > 1.5, the suspect specimen will be rejected.

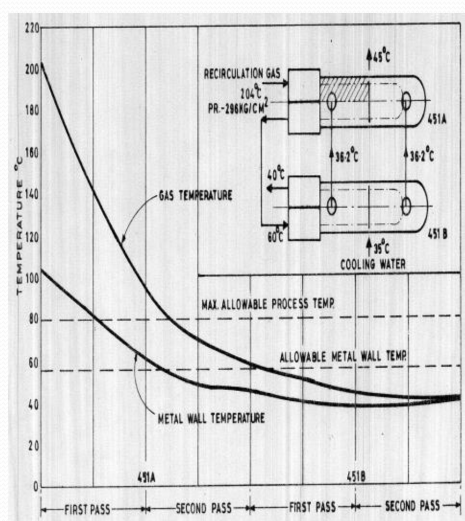
Stress Corrosion Cracking : presence of Chlorides

Equipment: WATER COOLER (Recirculation Gas Cooler)
Tube MOC: SS 304

Failure: Observed circumferential cracks on tubes near gas inlet in one exchanger

Failure Root Cause
SCC resulting from high level of chlorides in water coincident with high temperature & high stresses.

Conclusion / Recommendation
Selection of suitable material based on the operating conditions (Temp., Stresses, Chloride levels etc.)



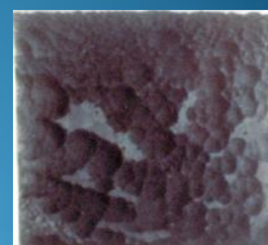
Chloride level 25-55 ppm

Metal Dusting

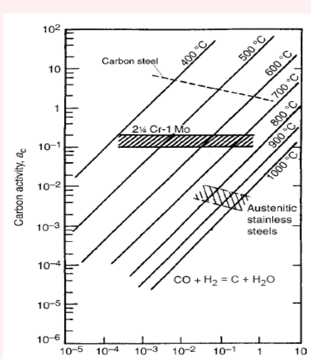
Metal dusting

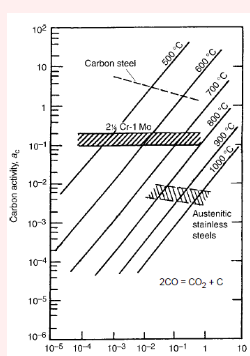
- In many chemical and petrochemical applications the fluids are carbonaceous in nature resulting in carbon deposition
- Metal dusting is catastrophic carburisation of metals in temperature of 400 to 900 °C
- It occurs in the presence of CO, CO_2, CH_4 environments at high temperatures
- Stagnant areas are more prone to attack & is unpredictable
- **Steam** and **sulphur** addition can help in preventions
- Fluid composition plays a vital role
- Carbon activity of the environment and alloy determines the likelihood of an alloy to metal dusting

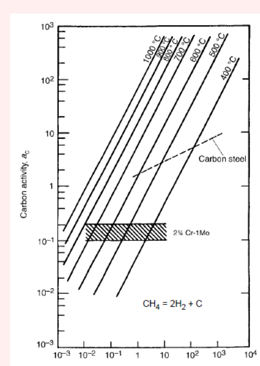
tube section of HK40 (cast 25%Cr–20%Ni steel)



Guideline in material selection







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Guideline in material selection

Metal Dusting

Case Study :

An experiment was conducted by Chiyoda corporation on a various material on metal dusting at different temperature

Environment : Test was carried on simulate ammonia plant atmosphere

Samples condition : Ground with 400# emery and electropolished

Material groups tested : carbon & Cr-Mo steel , ferritic SS, austenitic SS, nickel base alloy etc

Test temperature : Coupons were placed in quartz tube and heated to 447°C,497°C, 597°C, 697°C, 797°C by electric furnace and exposed to 66%H_2-17%CO-1%CO_2-17%H_2O and 500 hrs at ambient pressure

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Guideline in material selection

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Metal Dusting

Outcome of the results

A: No metal dusting

B: slight carburizing

C: metal dusting and/ or slight carburization

D: severe oxidation even if metal dusting occurred

Material	Temperature K(°C)				
	720 (447)	770 (497)	870 (597)	970 (697)	1070 (797)
2.25Cr-1Mo	A	B	C	D	D
9Cr-1Mo	A	B	C	D	D
SS 304	A	A	C	C	C
Alloy 800 H	A	B	C	C	C
Inconel 601	A	A	B	B	B
Inconel 625	A	A	A	A	A
HP-NbTi	A	A	C	C	C

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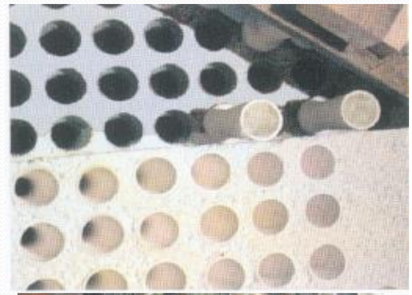
Ferrules

- Ferrules are required to protect the tube to tubesheet joint from impingement of hot gas.

- Typical MOC for ferrules are
  - Incoloy 800 /800H
  - Inconel 601, 690
  - Ceramic



Urea grade material developments

316L UG
- -Less cost
- -O2 for passivation
- -Susceptible to condensation corrosion & SCC
- -Ferrite < 1%

25Cr-22Ni-2Mo
- Higher cost
- O2 for passivation
- Ferrite<1%
- Increased Corrosion resistance due to higher Cr & Mo
- Less susceptible to condensation corrosion
- Susceptible to SCC

Duplex stainless steel
- -O2 for passivation is not required
- -Ferrite 30-70%
- -Negligible corrosion
- -Resistance to SCC
- -No active & condensation corrosion
- -Reduces total equipment wt due to higher strength
- -Zero Oxygen makes plant intrinsically safe

Process Licensor

STAMICARBON	• SS 25-22-2 • SAFUREX(SANDVIK+STAMICARBON)
SNAMPROGETTI	• SS 25-22-2 • BIMETALLIC TUBES (SS+ZIRCONIUM) • TITANIUM
TOYO ENGINEERING CORPORATION (TEC)	• 316L UG • DP12 • DP28W (SUMITOMO + TEC)
UREA CASALE	• 316L UG • SS 25-2-2 • DP28W (Plan to tie up with TEC)

Urea grade materials

Material	Cr	Ni	Mo	W	N	Ferrite in %	Remarks
316L UG	16	13	2	-	0.1	<1	Austenite
25-22-2	25	22	2	-	-	<1	Austenite
DP28W	27	8	1	2.2	0.3	35-55	Duplex
SAFUREX	28	6	2	2	0.3	40-60	Duplex

Material	Tensile strength Mpa	Yield strength In Mpa	% of elongation	Remarks
316L UG	485	170	40	Austenite
25-22-2	585	275	30	Austenite
DP28W	800	550	15	Duplex
SAFUREX	800	650	25	Duplex

Effect of alloying elements

Cr is to improve the corrosion/oxidation resistance

Ni &N austenitic stabilizer -maintain duplex phase

Mo added to increase the pitting corrosion resistance. but it enhances sigma phase formation . So W is added by reducing Mo content

Nitrogen is added to increase pitting & crevice corrosion resistance , strength/toughness , delays the formation of intermetallic precipitates and assists to get uniform distribution of chromium in the duplex phase

Duplex - gives ferrite phase strength & Austenite phase toughness

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Corrosion requirements

Material	Corrosion test	Test Medium	Corrosion rate in mm/month	Depth of attack in microns
316L UG	Huey test (48 Hrs x 5 Cycles)	65% Nitric acid	0.05	90 to 200
25-22-2	Huey test (48 Hrs x 10 Cycles)	65% Nitric acid	0.015	70
SAFUREX	Streicher test (120 Hrs)	50% sulfuric acid + 2.5 wt % Ferric sulfate	0.06	70
DP28W	Huey test (48 Hrs x 5 Cycles)	65% boiling nitric acid	0.015	50

- Material procurement shall address appropriate corrosion test, corrosion rate and depth of attack
- Same shall be applied to welding consumables l

Heat Treatment simulation

- During base material ordering based on fabrication heat treatment, base material shall be simulated to ensure properties of material as per material specification
- Heat treatment for simulation shall include all thermal treatments of the material during fabrication exceeding 900°F(480°C)
- The vessel Manufacturer shall specify the temperature, time, and cooling rates to which the material will be subjected during fabrication
- The total time at temperature shall be at least 80% of the total time at temperature during actual heat treatment of the product and may be performed in a single cycle
- Thermal treatment of material is not intended to include such local heating as thermal cutting, preheating, welding, or heating below the lower transformation temperature of tubing and pipe for bending or sizing.

Heat Treatment simulation

- Materials conforming to one of the specifications listed in P-No. 1 Group Nos. 1 and 2 of QW-422 and all carbon and low alloy steels used in the annealed condition as permitted by the material specification are exempt from the requirements of simulation for heat treatment below lower transformation temperature
- All thermal treatments which precede a thermal treatment that fully austenitizes the material need not be accounted for by the specimen heat treatments, provided the austenitizing temperature is at least as high as any of the preceding thermal treatments.
- Generally as material simulation we give one cycle for fabrication+ one for repair +one cycle for any repair at site
- As per ASME , material is simulated for maximum PWHT condition including all three cycles
- AS per API , materials shall besimulated for minimum and maximum PWHT condition for three cycles

Material considerations for Fabrication/ Repair

- Material ordered with upper limit on YS to facilitate forming/rolling based on the press capacity
- LAS consumables procured with guarantee/ actual testing for mechanical properties (UTS, YS & Toughness) with minimum and maximum simulation PWHT
- LAS welding Consumable – hardness restriction
- Weld overlay – welding consumables procured with ferrite restriction (for example 3 to 8 FN for SS 347)
- CS/ LAS Tube sheets are overlaid with SS or Inconel to facilitate plugging incase of leakage at site
- In case of auto-geneous tube-to-tubesheet and tube-to-tube orbital welds, tube and tubesheet ordered with controlled Sulphur limit (50 to 100 ppm) to account for the cast to cast variation
- LAS Nozzles are attached with CS spool pieces. This will permit repair at site without any PWHT incase of any modification at site

Material considerations for repairs.

- When considering repair/ re-weld operations of materials, consideration must be given to the following:
  - Type of material and Service
  - Weldability of the material
  - Material thickness
  - PWHT requirement & availability of soak
  - Residual stress & Distortion related problems

- Materials such as mild, low carbon and carbon-manganese steels, are considered to be very tolerant to heat input and may accept at least two or more re-weld operations.

- If the material is known to be metallurgically 'sensitive' to heat input, which could result in degradation of both the HAZ and weld deposit, it then becomes a question of complete removal of the welded joint and replacement with an inserted section.

Material consideration for repairs.

- In the case of low alloy steels, re-welds will be governed by the heat-treated condition in which they were supplied. For the Cr-Mo steels, up to two re-welds may be carried out, but consideration needs to be given to the post-weld heat treatment operations and possible resultant degradation of the welded joint.
- With the 3xx series stainless steels, two re-welds may be tolerated, but in the case of the duplex and super duplex stainless steels, only one re-weld operation is advisable, and then extreme care and control over the heat input is necessary. Ideally, for these complex metallurgical materials, avoidance of any form of re-weld operation is favoured.

Thank You ....

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