Lesson 18

RP 571 Damage Mechanism Affecting Fixed Equipment in the Refining Industry

The following lesson will give an example a type of failure from each section and category listed on the API 510 exam Body of Knowledge. This will only be a brief introduction, a practice exercise covering all of the topics has been provided in the study material.

The damage mechanisms are divided into the following categories:

- Mechanical and Metallurgical Failure
- Uniform or Localized Loss of Thickness
- High Temperature Corrosion
- Environment Assisted Cracking
- Refinery Industry Damage Mechanisms

From these four groups you are responsible for,

a) Mechanical and Metallurgical Failure

- 4,2.3 - Temper Embrittlement
- 4,2.7 - Brittle Fracture
- 4,2.9 - Thermal Fatigue
- 4,2.14 - Erosion / Erosion-Corrosion
- 4,2.16 - Mechanical Failure

a) Uniform or Localized Loss of Thickness

- 4,32 – Atmospheric Corrosion
- 4,3.3 - Corrosion Under Insulation (CUI)
- 4,3.4 - Cooling Water Corrosion
- 4,3.5 - Boiler Water Condensate Corrosion

b) High Temperature Corrosion

- 4,4.2— Sulfidation

c) Environment Assisted Cracking

- 4,5.1 Chloride Stress Corrosion Cracking (CI-SCC)
- 4,52 Corrosion Fatigue
- 4,5.3 Caustic Stress Corrosion Cracking (Caustic Embattlement)

d) Refinery Industry Damage Mechanisms

1. Environment Assisted
    - 5,1.2.3 - Wet H25 Damage Blistering/HIC/SOHICGCC)

2. Other Mechanisms
    - 5,1.3.1 - High Temperature Hydrogen Attack (HTHA)

Mechanical and Metallurgical Failure

4.2.3 Temper Embrittlement

Description of Damage

- Temper embrittlement is the reduction in toughness due to a metallurgical change that can occur in some low alloy steels as a result of long-term exposure in the temperature range of about 650 °F to 1100 °F (343 °C to 593 °C).

- Although the loss of toughness is not evident at operating temperature, equipment that is temper embrittled may be susceptible to brittle fracture during start-up and shutdown.

Affected Materials

- Primarily 2.25Cr-1 Mo low alloy steel, 3Cr-1 Mo (to a lesser extent), and the high-strength low alloy Cr- Mo-V rotor steels.

- Older generation 2.25Cr-1Mo materials manufactured prior to 1972 may be particularly susceptible. Some high strength low alloy steels are also susceptible.

- The C-0.5Mo and 1.25Cr-0.5Mo alloy steels are not significantly affected by temper embrittlement.

Affected Units or Equipment

- Equipment susceptible to temper embrittlement is most often found in:
- Hydroprocessing units, particularly reactors.
- Hot feed/effluent exchanger components, and hot HP separators.
- Catalytic reforming units (reactors and exchangers), FCC reactors, coker and visbreaking units.
- Welds in these alloys are often more susceptible than the base metal and should be evaluated.

Appearance of Damage

- Temper embrittlement is a metallurgical change that is not readily apparent and can be confirmed through impact testing. Damage due to temper embrittlement may result in catastrophic brittle fracture.
- Temper embrittlement can be identified by an upward shift in the ductile-to-brittle transition temperature measured in a Charpy V-notch impact test, as compared to the non-embrittled or de-embrittled material.

Inspection and Monitoring

- A common method of monitoring is to install blocks of original heats of the alloy steel material inside the reactor. Samples are periodically removed from these blocks for impact testing to monitor progress of temper embrittlement or until a major repair issue arises.

- Process conditions should be monitored to ensure that a proper pressurization sequence is followed to help prevent brittle fracture due to temper embrittlement.

Uniform or Localized Loss of Thickness

4.3.2 Atmospheric Corrosion

Description of Damage

- A form of corrosion that occurs from moisture associated with atmospheric conditions. Marine environments and moist polluted industrial environments with airborne contaminants are most severe. Dry rural environments cause very little corrosion.

Affected Materials

- Carbon steel, low alloy steels and copper alloyed aluminium.

Affected Units or Equipment

- Piping and equipment with operating temperatures sufficiently low to allow moisture to be present.
- Paint or coating system in poor condition.
- Equipment may be susceptible if cycled between ambient and higher or lower operating temperatures.
- Equipment shut down or idled for prolonged periods unless properly mothballed.
- Tanks and piping are particularly susceptible. Piping that rests on pipe supports is very prone to attack due to water entrapment between the pipe and the support.
- Bimetallic connections such as copper to aluminium electrical connections.

Appearance

- The attack will be general or localized, depending upon whether or not the moisture is trapped.
- If there is no coating or if there is a coating failure, corrosion or loss in thickness can be general.
- Localized coating failures will tend to promote corrosion.
- Metal loss may not be visually evident, although normally a distinctive iron oxide (red rust) scale forms.

Inspection and Monitoring

- VT and UT are techniques that can be used.

High Temperature Corrosion [400°F (204°C))

Sulfidation
(Also known as Sulfidic Corrosion)

Description of Damage

Corrosion of carbon steel and other alloys resulting from their reaction with sulphur compounds in high temperature environments. The presence of hydrogen accelerates corrosion.

Affected Materials

- All iron-based materials including carbon steel and low alloy steels, 300 Series SS and 400 Series SS.
- Nickel base alloys are also affected to varying degrees depending on composition, especially chromium content.
- Copper base alloys form sulphide at lower temperatures than carbon steel.

Affected Units or Equipment

- Sulfidation occurs in piping and equipment in high temperature environments where sulphur-containing streams are processed.
- Common areas of concern are the crude, FCC, coker, vacuum, visbreaker and hydroprocessing units.
- Heaters fired with oil, gas, coke and most other sources of fuel may be affected depending on sulphur levels in the fuel.
- Boilers and high temperature equipment exposed to sulphur-containing gases can be affected.

Appearance of Damage

- Depending on service conditions, corrosion is most often in the form of uniform thinning but can also occur as localized corrosion or high velocity erosion-corrosion damage.
- A sulphide scale will usually cover the surface of components. Deposits may be thick or thin depending on the alloy, corrosiveness of the stream, fluid velocities and presence of contaminants

Inspection and Monitoring

- Process conditions should be monitored for increasing temperatures and/or changing sulfur levels.

- Temperatures can be monitored through the use of tube skin thermocouples and/or infrared thermography.

- Evidence of thinning can be detected using external ultrasonic thickness measurements and profile radiography.

- Proactive and retroactive PMI programs are used for alloy verification and to check for alloy mix-ups in services where Sulfidation is anticipated.

Environment - Assisted Cracking

Chloride Stress Corrosion Cracking

A cracking process that requires the simultaneous action of a corrodent and sustained tensile stress. This excludes corrosion-reduced sections that fail by fast fracture. It also excludes inter-crystalline or trans-crystalline corrosion, which can disintegrate an alloy without applied or residual stress. Stress-corrosion cracking may occur in combination with hydrogen embrittlement.

Description of Damage

Surface initiated cracks caused by environmental cracking of 300 Series Stainless Steel and some nickel base alloys under the combined action of:

- tensile stress
- temperature
- Aqueous chloride environment
- The presence of dissolved oxygen increases chances for cracking.

Affected Materials

- All 300 Series Stainless Steels are highly susceptible.
- Duplex stainless steels are more resistant.
- Nickel base alloys are highly resistant

Affected Units or Equipment

- All 300 Series SS piping and pressure vessel components in any process units are susceptible to CUI-SCC.
- Cracking has occurred in water-cooled condensers and in the process side of crude tower overhead condensers.
- Drains in hydroprocessing units are susceptible to cracking during **start-up/shutdown** if not properly purged.

Appearance of Damage

- Surface breaking cracks can occur from the process side or externally under insulation.
- The material usually shows no visible signs of corrosion.
- Characteristic stress corrosion cracks have many branches and may be visually detectable by a craze/cracked appearance of the surface.
- Metallography of cracked samples typically shows brandied transgranular cracks. Sometimes intergranular cracking of sensitized 300 Series SS may also be seen.
- Welds in 300 Series SS usually contain some ferrite, producing a duplex structure that is usually more resistant to CUI-SCC.
- Fracture surfaces often have a brittle appearance.

45.1.7 inspection and Monitoring

- Cracking is surface connected and may be detected visually in some cases.

- PT or phase analysis EC techniques are the preferred methods.

- Eddy current inspection methods have also been used on condenser tubes as well as piping and pressure vessels.

- Extremely fine cracks may be difficult to find with PT. Special surface preparation methods, including polishing or high-pressure water blast, may be required in some cases, especially in high pressure services.

- UT

- Often, RT is not sufficiently sensitive to detect cracks except in advanced stages where a significant network of cracks has developed.

Refining Industry Damage Mechanisms
Environment - Assisted Cracking

Wei H2S Damage (Blistering/HIC/SOHIC/SSC)

Description of Damage

This section describes four types of damage that result in blistering and/or cracking of carbon steel and low alloy steels in wet H2S environments.

Hydrogen Blistering

- Hydrogen blisters may form as surface bulges on the ID, the OD or within the wall thickness of a pipe or vessel.

- The blister results from hydrogen atoms that form during the sulphide corrosion process on the surface of the steel, that diffuse into the steel, and collect at a discontinuity in the steel such as an inclusion or lamination.

- The hydrogen atoms combine to form hydrogen molecules and the pressure builds to the point where blister forms.

- Blistering results from hydrogen generated by corrosion, not hydrogen gas from the process stream.

Wet H2S Damage (Blistering/HIC/SOHIGSSC)

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, neighbouring 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".**

Hydrogen Induced Cracking (HIC) Cross-section of plate showing HIC damage in the shell of a trim cooler which had been cooling vapours off a HHPS vessel in a hydroprocessing unit.

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). They 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 sulphide stress cracks.

Wet H2S Damage (Blistering/HIC/SOHIC/SSC)
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 H2S.
- SSC is a form of hydrogen stress cracking resulting from absorption of atomic hydrogen that is produced by the sulphide corrosion process on the metal surface.
- SSC can initiate on the surface of steels in highly localized zones of high hardness in the weld metal and heat affected zones.
- Zones of high hardness can sometimes be found in weld cover passes and attachment welds which are not tempered (softened) by subsequent passes.
- PWHT is beneficial in reducing the hardness and residual stresses that render a steel susceptible to SSC.
- High strength steels are also susceptible to SSC, but these are only used in limited applications in the refining industry.
- Some carbon steels contain residual elements that form hard areas in the heat affected zones that will not temper at normal stress relieving temperatures. Using preheat helps minimize these hardness problems.

Affected Materials

- Carbon steel and low alloy steels.

Affected Units or Equipment

- Blistering, HIC, SOHIC and SSC damage can occur throughout the refinery wherever there is a wet H2S environment present.
- In hydroprocessing units, typical locations include fractionator overhead drums, fractionation towers, absorber and stripper towers, Compressor Interstage separators and knockout drums and various heat exchangers, condensers, and coolers.

Inspection and Monitoring

- Inspection for wet H2S damage generally focuses on weld seams and nozzles.
- Cracks may be seen visually, crack detection is best performed with WFMT, EC, RT or ACFM techniques. Surface preparation is required for WFMT but not for ACFM. PT cannot find tight cracks and should not be depended on.
- UT techniques including external SWUT can be used. SWUT is especially useful for volumetric inspection and crack sizing.
- Grinding out the crack or removal by thermal arc gouging is a viable method of crack depth determination.

Refinery Industry

Other Mechanisms

High Temperature Hydrogen Attack (HTHA)

Description of Damage

- High temperature hydrogen attack results from exposure to hydrogen at elevated temperatures and pressures. The hydrogen reacts with carbides in steel to fame methane (CH_4) which cannot diffuse through the steel.

- Methane pressure builds up, forming bubbles or cavities, micro fissures and fissures that may combine to form cracks.

- Failure can occur when the cracks reduce the load carrying ability of the pressure containing part.

Affected Materials

In order of increasing resistance.

1. Carbon steel
2. C-0.5Mo
3. Mn-0.5Mo
4. 1Cr-0.5Mo
5. 1.25Cr-0.5Mo
6. 2.25Cr-IMo
7. 2.25Cr-1Mo-V
8. 3Cr-IMo
9. 5Cr-0.5Mo and similar steels with variations in chemistry

Affected Units

- Hydroprocessing units, such as hydrotreaters (desulfurizers) and hydrocrackers, catalytic reformers, hydrogen producing units and hydrogen clean up units, such as pressure swing absorption units, are all susceptible to HTHA.

- Boiler tubes in very high-pressure steam service.

Appearance of Damage

- HTHA can be confirmed through the use of specialized techniques including metallographic analysis.

- In the early stages of HTHA, bubbles/cavities can be detected in samples by a scanning microscope.

- In later stages of damage, decarburization and for fissures can be seen by examining samples under a microscope and may sometimes be seen by in-situ metallography.

- Cracking and fissuring are intergranular and occur adjacent to pearlite (iron carbide) areas in carbon steels.

- Some blistering may be visible to the naked eye.

Inspection and Monitoring

- Damage may occur randomly in welds or weld heat affected zones as well as the base metal, making detection of HTHA extremely difficult.
- Ultrasonic techniques using a combination of velocity ratio and backscatter have been the most successful in finding fissuring and for serious cracking.
- Visual inspection for blisters on the inside surface may indicate methane formation and potential HTHA.
- HTHA may occur without the formation of surface blisters.
- Other forms of inspection, including WFMT and RT, are severely limited in their ability to detect anything except damage where cracking has already developed.