Remaining Life Assessment of Coker Heater Tubes

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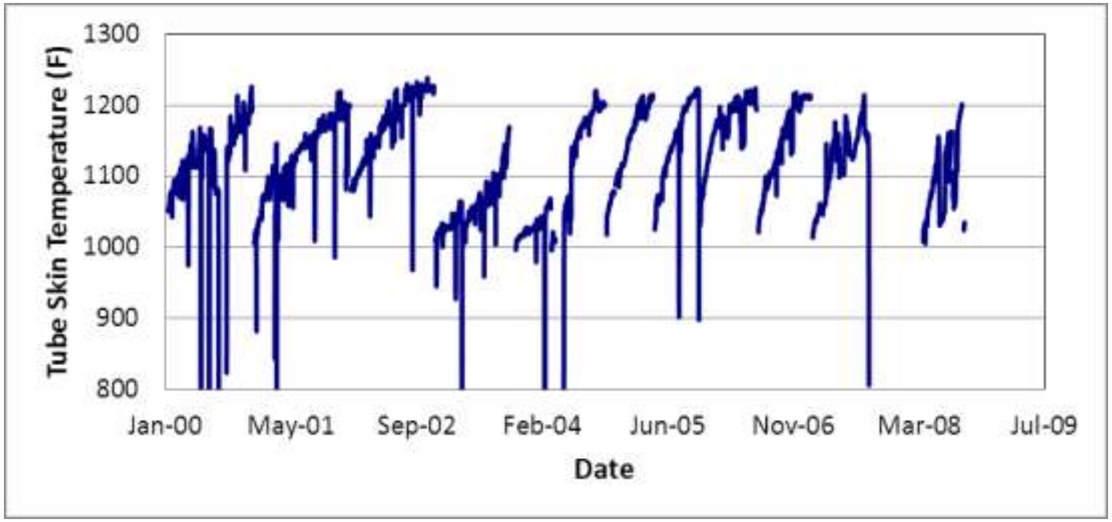
Overview

- Introduction
  - Coker Heaters
  - Creep
- Remaining Life Assessment
  - API 579-1 / ASME FFS-1 creep life assessment
- Creep Testing
  - Tube removal guidelines
  - Test Procedure
  - Case study
- Other Damage Mechanisms
- Concluding Remarks

Coker Heaters

- Operating conditions typically different from other fired heaters due to coking of radiant tubes
- Industry moving towards heavier/cheaper crudes
  - Larger quantities of vacuum residue
- Throughput limited by fouling
  - Frequent decoking cycles



Coker Heaters

- Creep is one of the most prominent damage mechanisms in coker heaters
- 9Cr-1Mo steel is the workhorse alloy in the refining industry
  - 5Cr-½Mo and 7Cr-½Mo in radiant sections of few old furnaces
  - Upgrades to austenitic stainless steel series or Incoloy 800H/HT are now common

What is Creep?

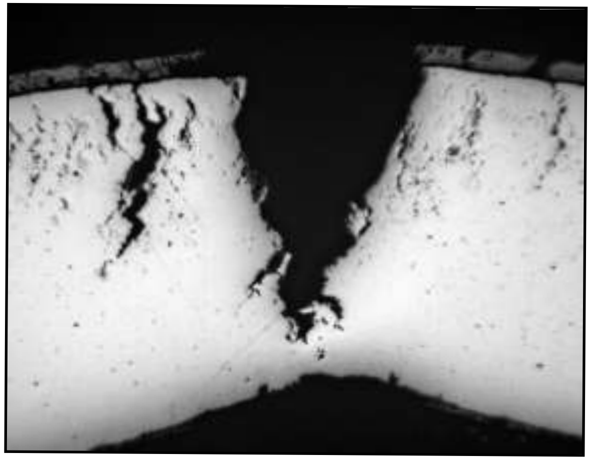
- Time-dependent permanent inelastic strain in materials when subjected to stresses below yield at elevated temperatures

$$\varepsilon_c = f(\sigma, t, T)$$

$$\dot{\varepsilon}_c = A\sigma^n \exp\left(\frac{-Q}{RT}\right)$$

Bailey-Norton steady state creep law

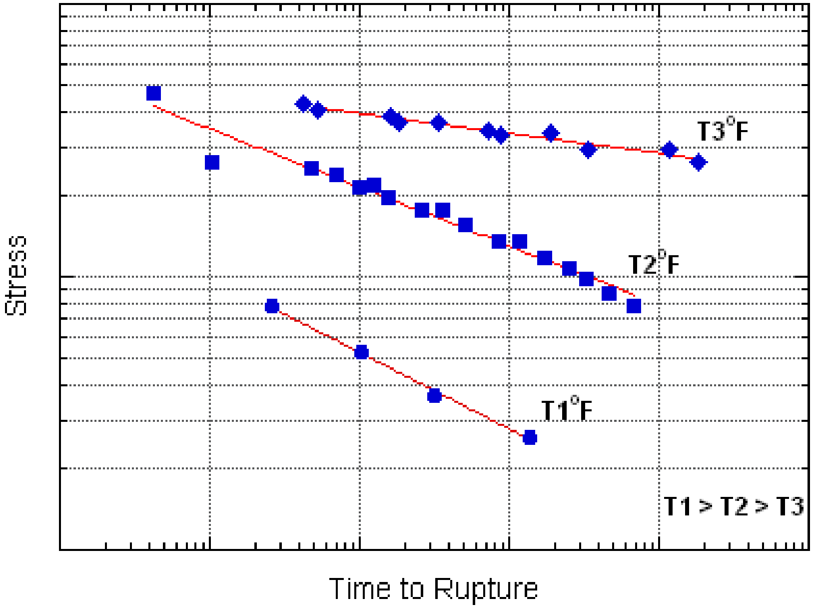
- Creep properties are determined from stress-rupture tests and/or accelerated creep tests

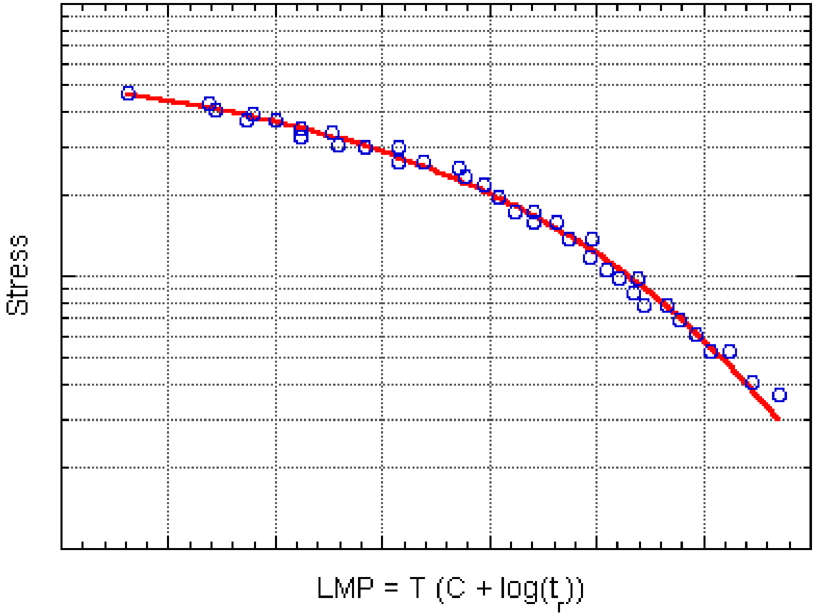


Larson-Miller Parameter

- Time-Temperature parameter developed in the early 1950s by F. R. Larson and J. Miller in order to extrapolate short-term rupture test results to long-term predictions

$$LMP = T(C + \log t_r)$$





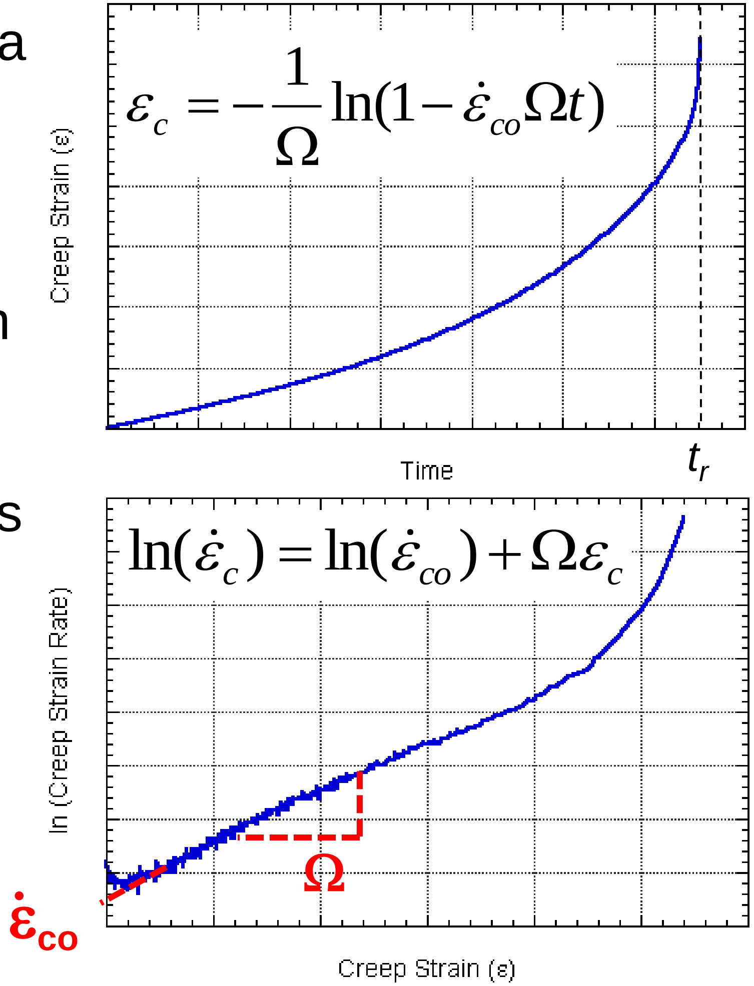
MPC Omega Method

- Based on the concept that strain rate is a direct gage of creep damage

$$\dot{\varepsilon}_c = \dot{\varepsilon}_{co} \exp(\Omega \varepsilon_c)$$

- Practical engineering alloys used in high temperature applications display little or no primary or secondary creep, residing in the tertiary range for most of their lives
- Ω is the creep damage coefficient and defines the rate at which the strain rate accelerates with increasing strain
- It is not required to run creep tests to rupture

$$t_r = \frac{1}{\dot{\varepsilon}_{co} \Omega_m}$$



Modeling Creep Behavior

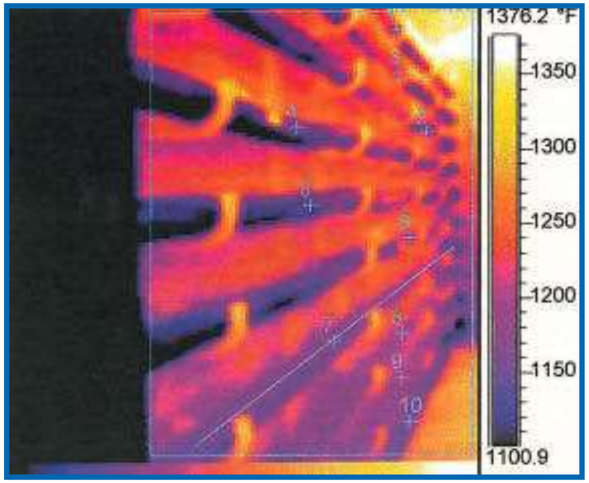
- Both LMP and Omega are fairly easy to use and are applicable to a number of engineering alloys
- LMP and MPC Omega are <u>not</u> the only methods available model creep behavior
    - These are the only two methods provided in API 579-1 / ASME FFS-1
- Neither methods are any more accurate than some of the other approaches that have been proposed
    - Manson-Haferd
    - Orr-Sherby-Dorn
    - Monkman-Grant

Why Do Creep Life Assessment?

- Determine how much life is remaining in the tubes
- Screen for creep damage prior to shutdowns to prevent/limit costly inspection/testing
- Determine if the furnace can be operated at higher temperatures
  - Higher EOR (end of run) temperatures are often desired in coker heaters to reduce the frequency of decoking cycles
  - Creep life assessment can show where operating limits should be set to maximize throughput vs. risk of failure

Inputs for Heater Tube Assessment

- Design Data
  - Material of construction
  - Tube size and schedule
- Service History
  - Tube metal temperatures
    - Thermocouple data and/or infrared data
  - Pressure
    - Inlet pressure and pressure drop
  - Corrosion
    - Corrosion rate and replacement history
    - Retirement thickness
  - Upsets



API 579-1 / ASME FFS-1 Creep Life Assessment

- Part 10 provides assessment procedures for pressurized components operating in the creep range
- Methodologies are provided to compute accumulated creep damage at each time increment where the component is subjected to a specific stress-temperature combination
  - Rupture data in terms of Larson-Miller parameter
  - MPC Project Omega data
- Based on a linear damage accumulation model

Remaining Life Calculations

- Remaining life calculated for each time increment ${}^{n}t$

<u>MPC Omega</u>

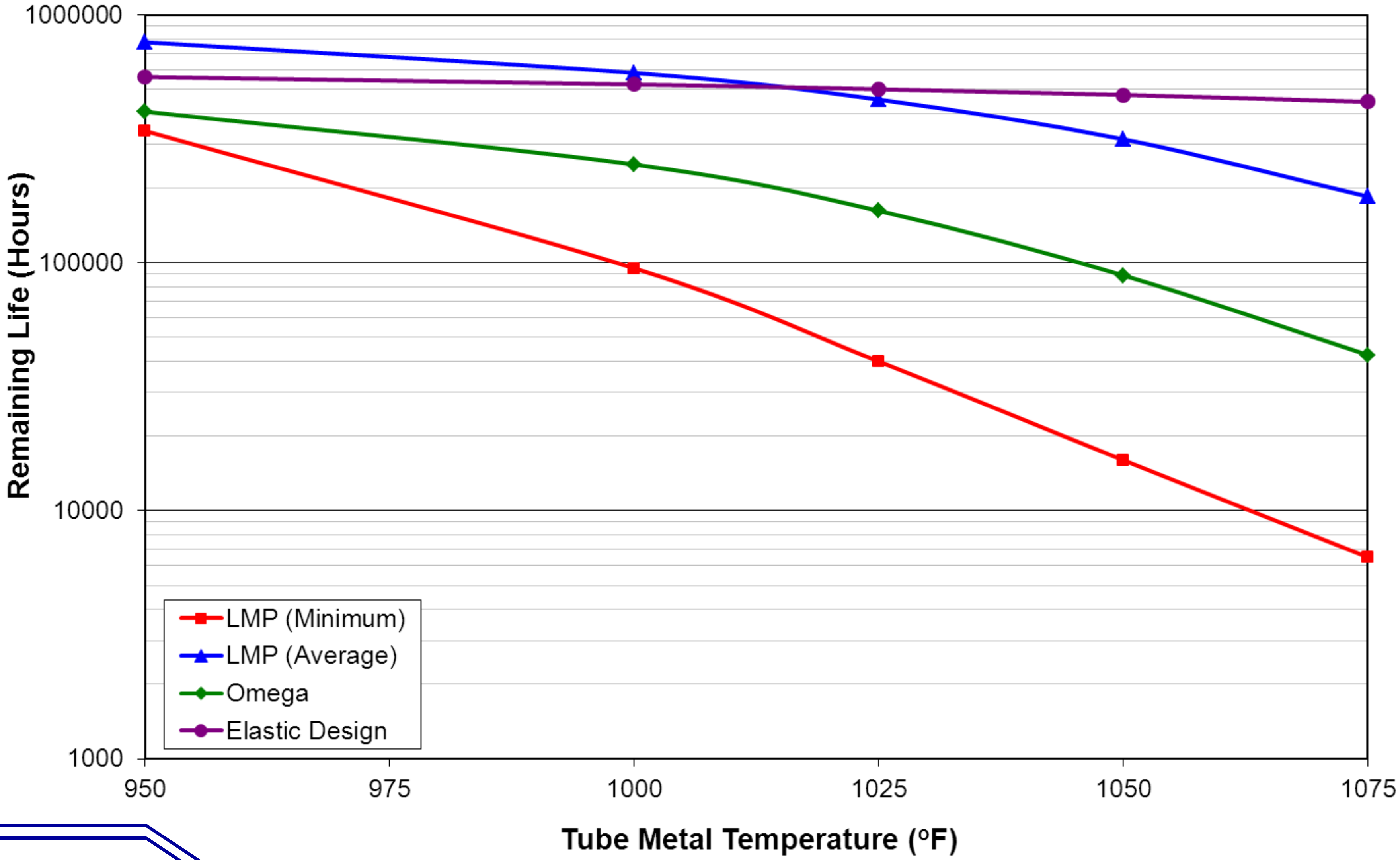
$$ {}^{n}L = \frac{1}{\dot{\varepsilon}_{co}\Omega_{m}} $$

<u>LMP (US Customary Units)</u>

$$ \log_{10} {}^{n}L = \frac{1000 \times LMP({}^{n}S_{eff})}{({}^{n}T + 460)} - C_{LMP} $$

- Total damage fraction $$ D_{c}^{total} = \sum_{n=1}^{N} \frac{{}^{n}t}{{}^{n}L} $$
- Creep life is fully consumed when the accumulated creep damage fraction equals 1.0
  - API 579-1 / ASME FFS-1 adds a safety margin (useful life consumed at D = 0.8)

Example: Remaining Life Results



Why Do Creep Testing?

- Precise description of the furnace operating history is not available
  - Reliable assessments cannot be made without accurate history
- Tubes have (or are suspected to have) suffered in-service degradation
  - Visual indications of creep damage are not always present
- Life assessment based on API 579-1 / ASME FFS-1 creep properties predicted that the tubes are near end of life
  - Testing provides creep properties specific to tubes being analyzed

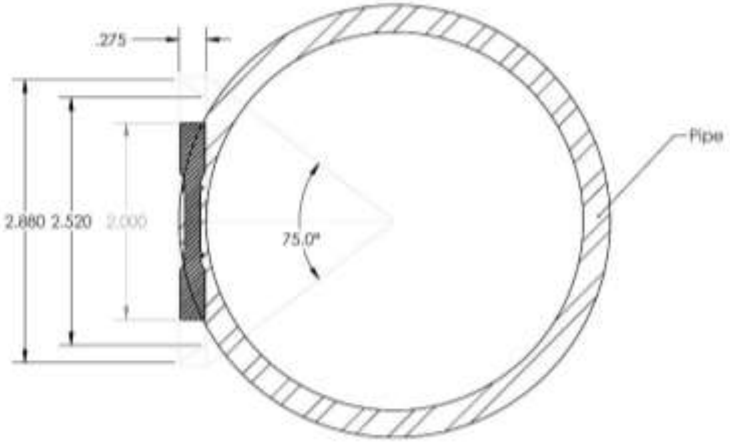
Guidelines for Tube Removal

- Sample from the areas exposed to the highest temperature regions that will be remaining in service
    - Use combination of IR data, thermocouple data, tube visual inspection, thickness measurements, and bulging checks (visual, strapping, lamping, and/or crawlers)
- Clearly mark the tubes before removal
    - Location in the heater (asset number, pass, elevation, distance to closest thermocouple, etc.)
    - Fire-side & back-side (if applicable)

- Testing the wrong tubes could be worse than not testing at all!
- Tube sample should be a minimum of 18” long if cold cut, or 24” long if torch cut

Accelerated Creep Testing

- Five specimens from each tube
    - Four hoop specimens from the fire-side
    - One axial specimen from the back-side
- The back-side specimen is a reference sample intended to represent, to the degree possible, a sample with minimal creep damage
- Specimens are typically nickel plated to limit oxidation

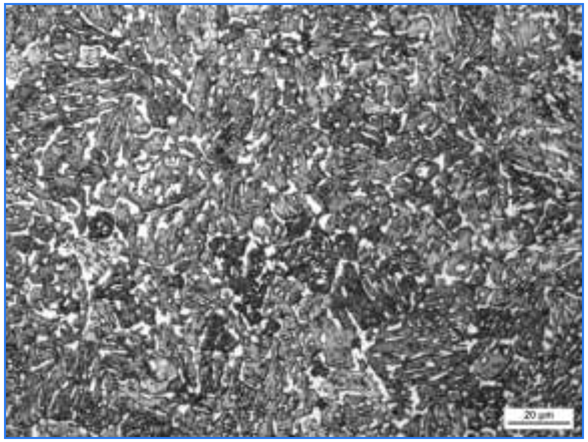


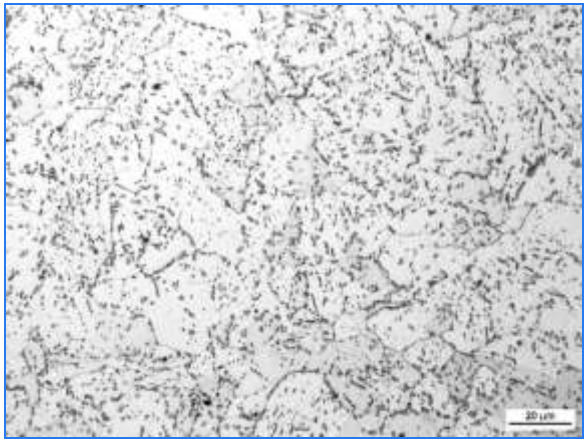
Creep Testing: Omega vs. LMP

- Omega method requires testing in two stages
  - Initial creep rate (ICR) more sensitive to changes in temperature and stress compared to Omega
    - Determine initial creep rate (ICR) at test conditions close to operating conditions
    - Determination of Omega requires further acceleration of test conditions
- LMP can be obtained by:
  - Testing to rupture
  - Predicting the time to rupture once a clear tertiary behavior is observed
- Materials that have not been thermally stabilized in service may not conform to the Omega model

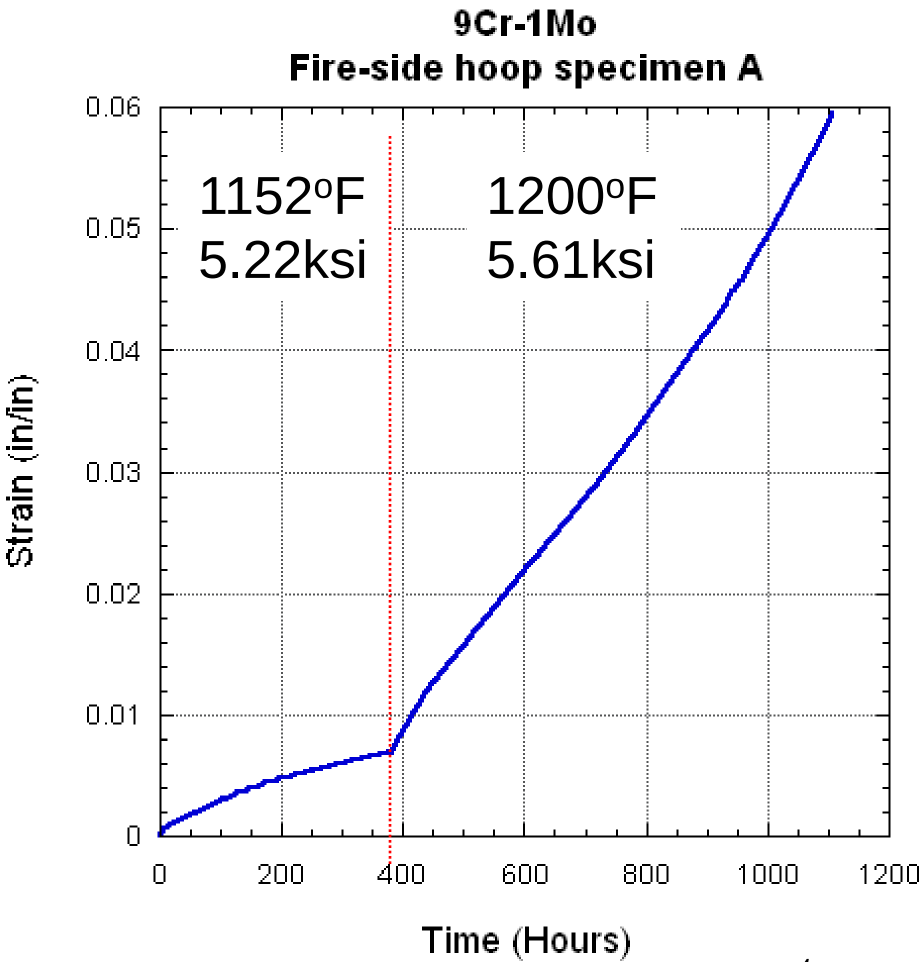
Case Study: Background

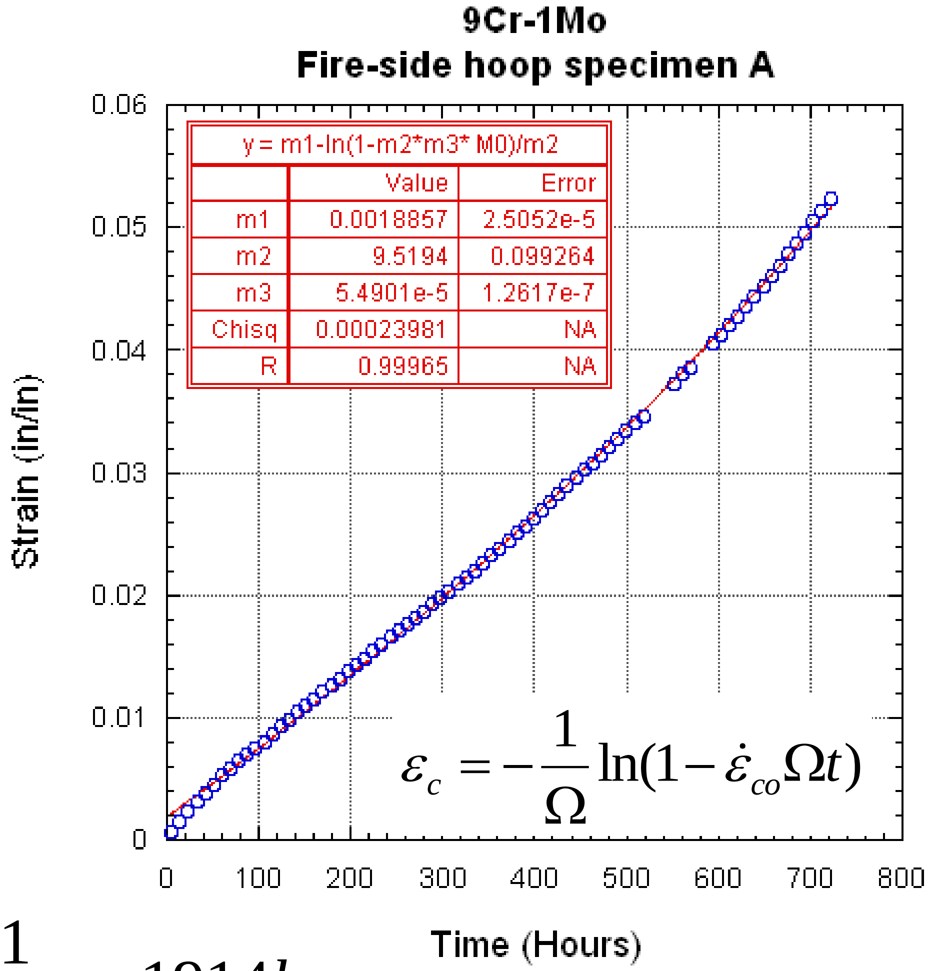
- Coker heater commissioned in 1982
- Tube Material: 9Cr-1Mo (SA213-T9)
- Tube Size: 3” Sch. 160
- Pressure: 450 psig
- Corrosion Rate: 3 mpy





Case Study: Fire-side Specimen





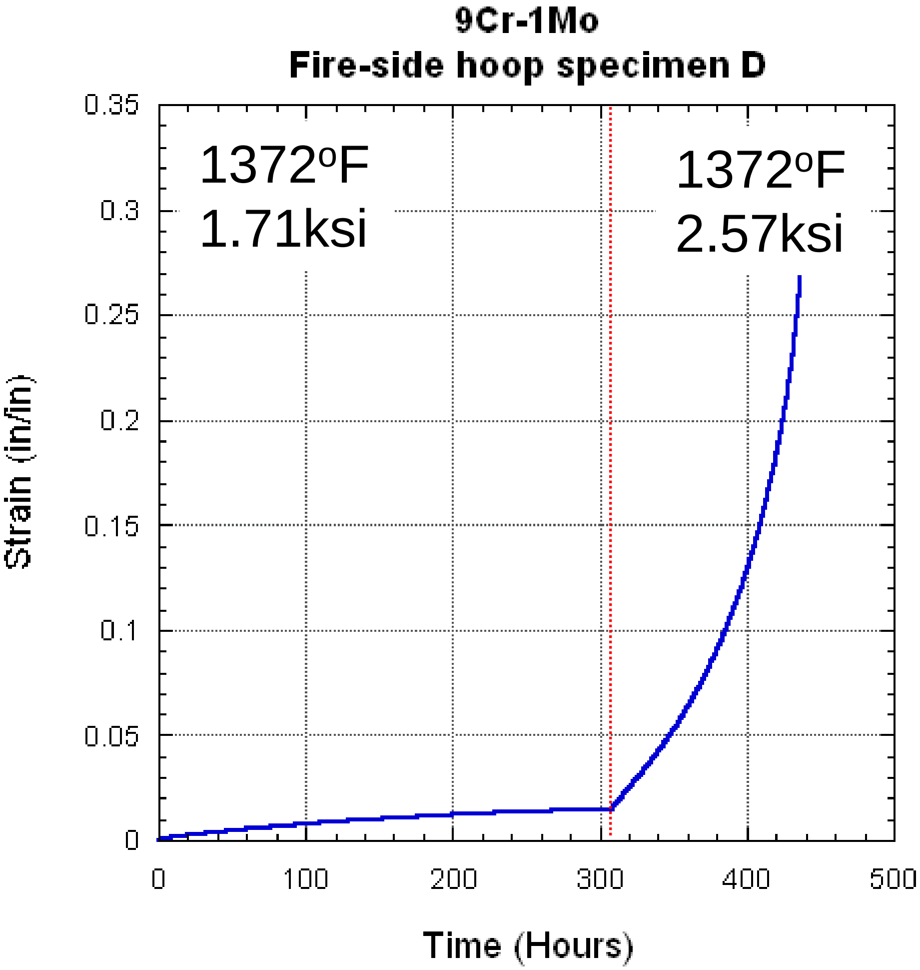
y = m1-ln(1-m2*m3* M0)/m2

	Value	Error
m1	0.0018857	2.5052e-5
m2	9.5194	0.099264
m3	5.4901e-5	1.2617e-7
Chisq	0.00023981	NA
R	0.99965	NA

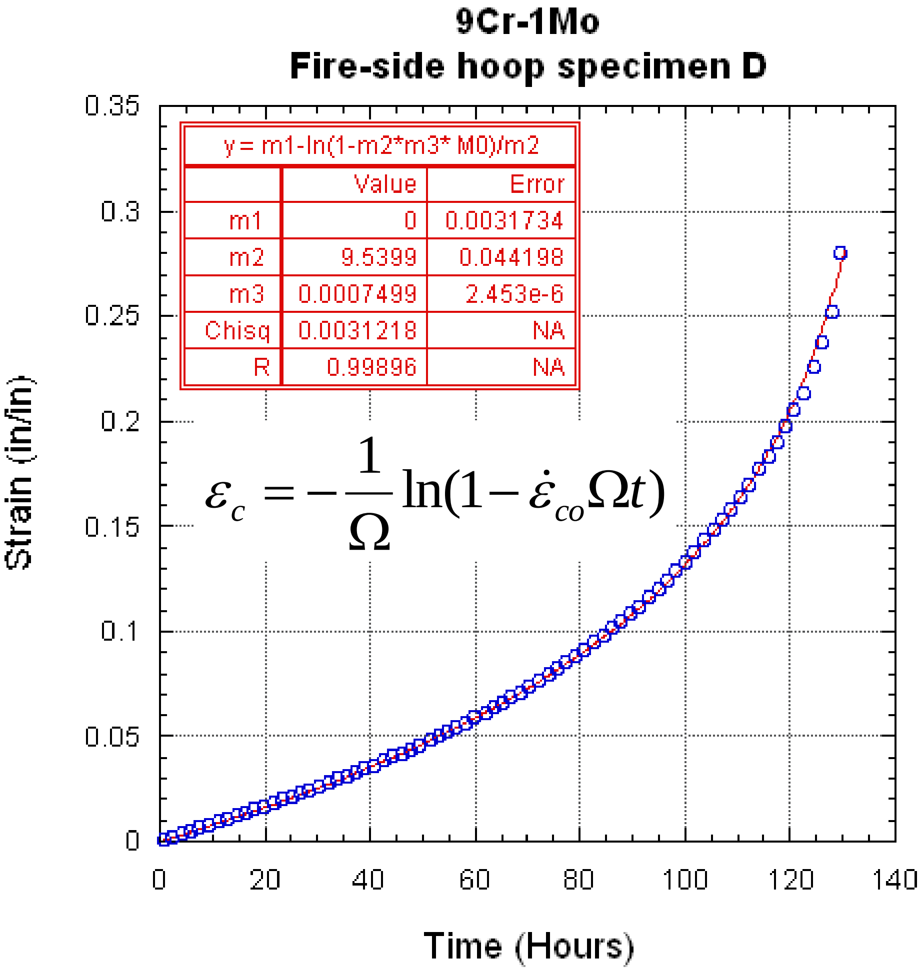
$$\varepsilon_c = -\frac{1}{\Omega}\ln(1-\dot{\varepsilon}_{co}\Omega t)$$

$$t_r = \frac{1}{\dot{\varepsilon}_{co}\Omega} = 1914 hrs.$$

Case Study: Fire-side Specimen



9Cr-1Mo
Fire-side hoop specimen D



9Cr-1Mo
Fire-side hoop specimen D

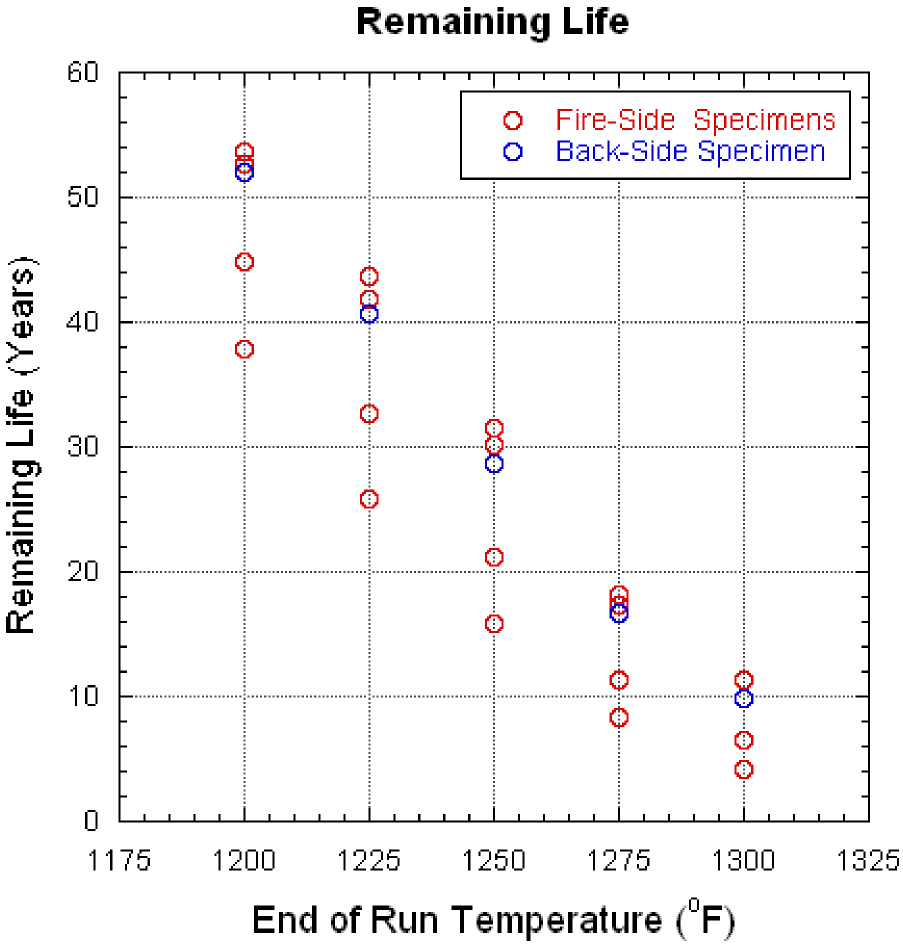
y = m1-ln(1-m2*m3* M0)/m2

	Value	Error
m1	0	0.0031734
m2	9.5399	0.044198
m3	0.0007499	2.453e-6
Chisq	0.0031218	NA
R	0.99896	NA

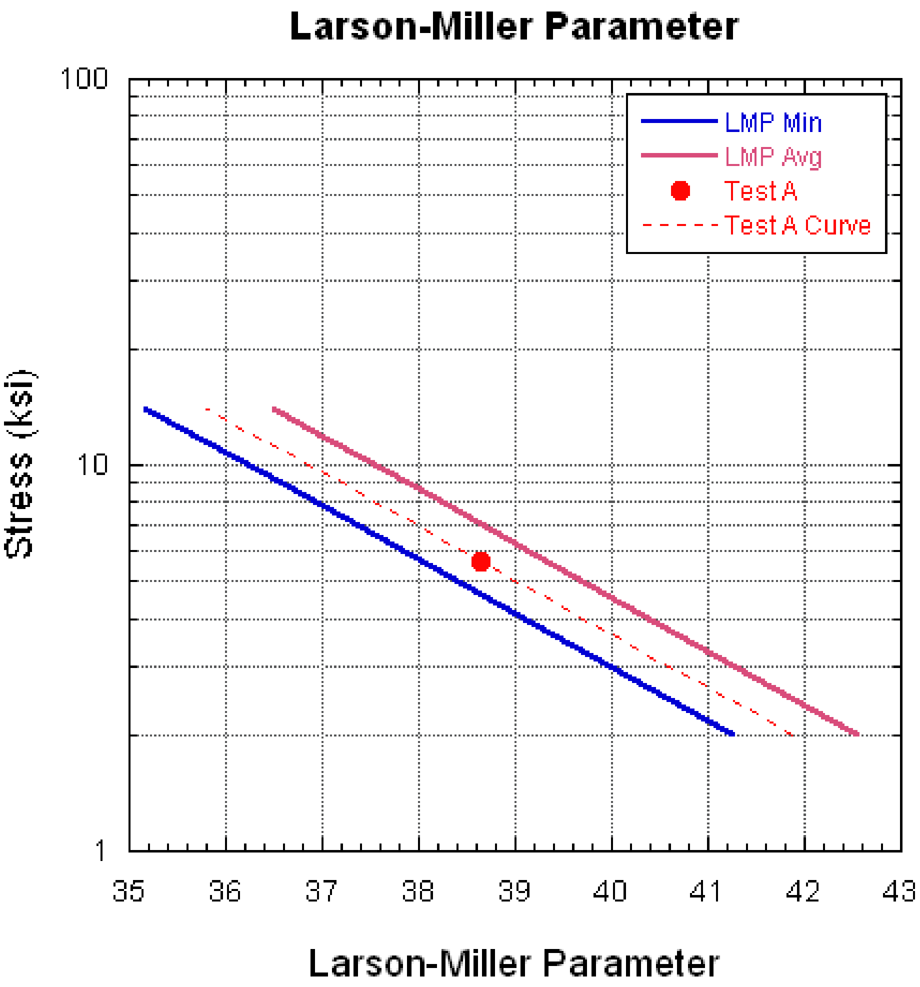
$$\varepsilon_c = -\frac{1}{\Omega}\ln(1-\dot{\varepsilon}_{co}\Omega t)$$

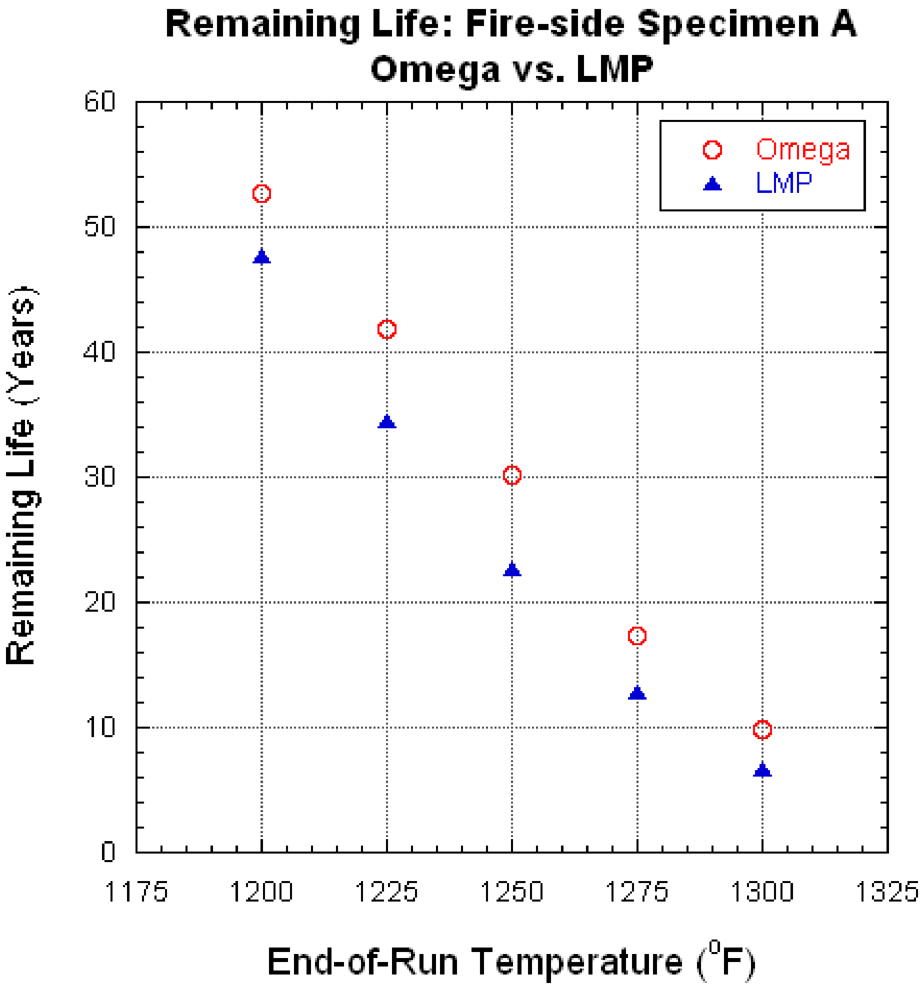
Case Study: Remaining Life

- Plenty of creep life left in the tube at EOR temperatures less than 1275ºF
- Test results show some scatter
- Back-side specimen test results lie within the scatter



Case Study: Omega vs. LMP





$$LMP = (T + 460)(20 + \log t_r) \times 10^{-3}$$

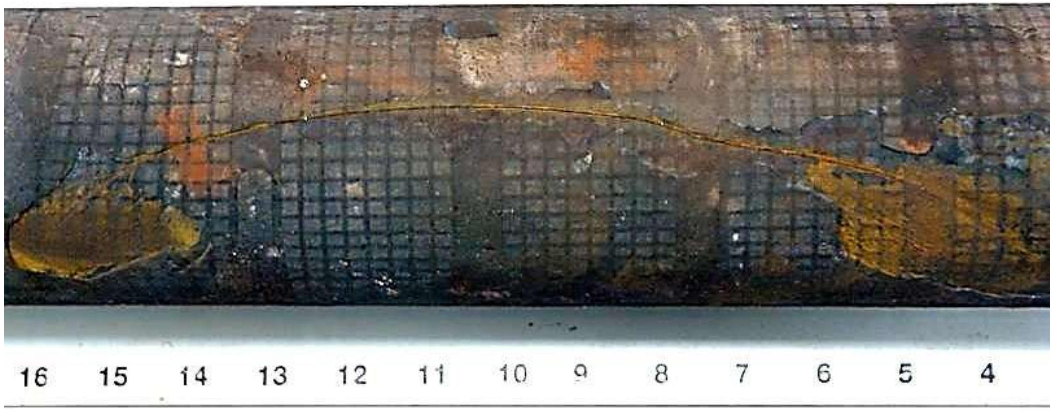
Other Damage Mechanisms

- Creep is not the only damage mechanism in coker heaters
  - Carburization
  - Sigma Phase (Stainless Steels)
  - External Oxidation
  - Sulfidation
  - Brittle Fracture
  - Erosion

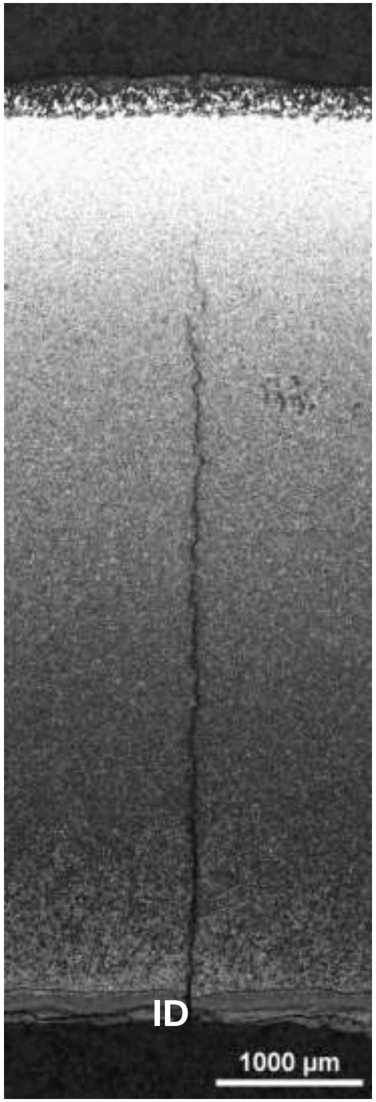
- Any of these damage mechanisms can lead to tube failures before creep life is consumed
  - Some might interact with creep, accelerating rupture

Carburization

- Coke deposits promote carburization on the ID
  - Carbon combines with carbide-forming elements in the alloy to form internal carbides
  - Occurs in CS, Cr-Mo alloys, 300 and 400 series SS typically above 1100°F
  - Reduces ambient temperature ductility, toughness, and weldability of the alloy

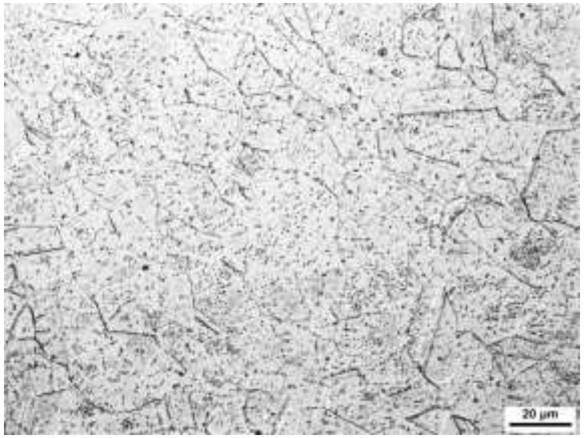


Brittle fracture in carburized 9Cr coker heater tube

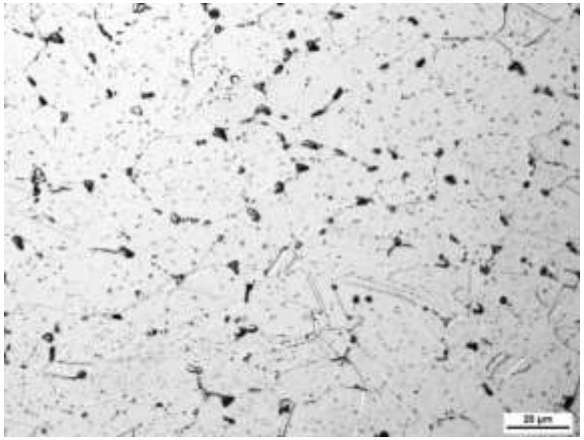


Sigma Phase Embrittlement

- Iron-Chromium intermetallic phase that forms in ferritic and austenitic stainless steels when exposed to 1050ºF - 1800ºF
  - Causes loss of ductility and embrittlement below 250ºF - 300ºF
  - May affect creep properties and reduce creep ductility



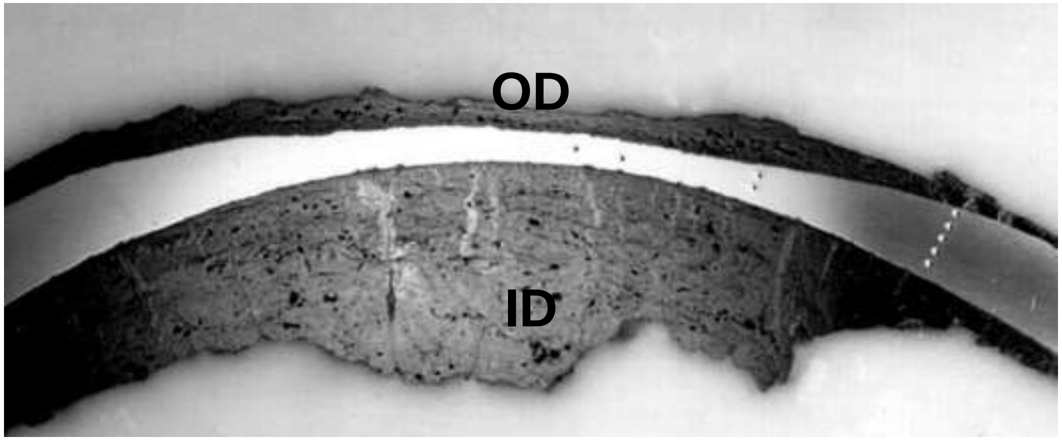
347H SS microstructure prior to exposure



347H SS microstructure after exposure

External Oxidation

- Conversion of metal to oxide scale in the presence of oxygen
  - Metal loss increases with increasing temperature
- Flame impingement causes localized heating
  - Increased oxidation on the OD
  - Increased coke formation on the ID



Erosion

- Tubes in Coker furnaces require frequent decoking processes to remove ID deposits (coke)
- Steam air and spall decoking are regularly used in refinery operations
  - Localized thinning at areas of high velocities decoking
  - Return bends are particularly affected
  - All alloys are susceptible

Challenges Predicting Life

- Establishing Life Limiting Degradation Mechanisms
- Defining Operating Conditions
  - Measuring tubes metal skin temperatures
  - Considering all applied loads and stresses affecting the tubes
- Selecting Material Creep Strength and Ductility
  - Industry data (literature)
  - Sampling and mechanical testing
- Gathering Inspection Data and Setting Variables Affecting Remaining Life Calculation
  - Corrosion rates
  - Time increment

Concluding Remarks

- Creep becomes more and more relevant as heaters age and profit margins push process limits
- Useful life can be prolonged with a combination of adequate inspection program, life assessment calculations and process changes
- Accelerated creep testing can be employed to shift the operating history of the tubes
- Other possible damage mechanisms must not be overlooked

Contact Information

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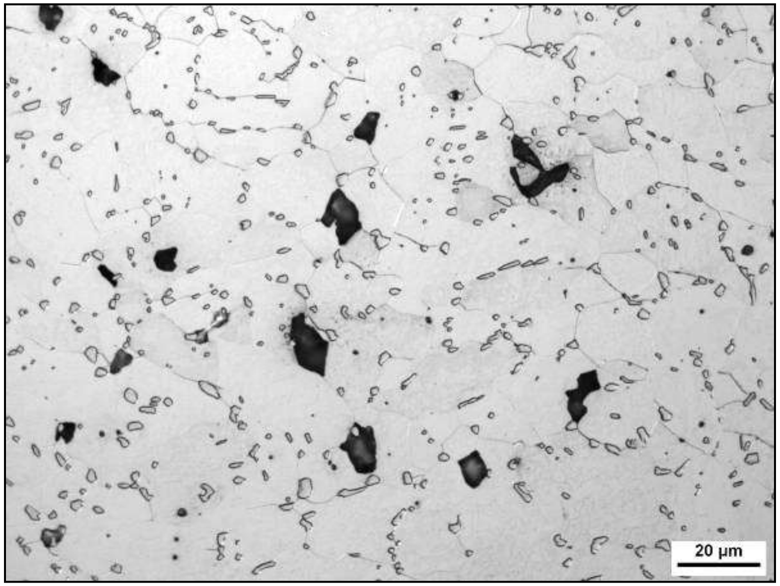

Creep voids in 9Cr-1Mo steel