The Impact of HPHT Conditions Upon Metallic Materials

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Problem

Higher Pressure results in:

- Higher stress levels
- Higher strength materials – increased cracking potential
- Strength to weight ratio

Higher Temperature result in:

- Strength reductions
- More metal movement – growth
- More corrosive, increased cracking

Engineering Materials - Drilling

- Carbon & Low Alloy Steels – most applications require YS 110 – 150 ksi
- Aluminum alloys – 30 – 40 ksi YS
- Titanium Alloys – 110 – 140 ksi YS

- API Drill Pipe Chemistry Requirement:
  - 0.030 Phosphorus max; 0.030 Sulfur max

Low Alloy Steels

- Primary materials used to manufacture drilling equipment are low alloy carbon steels
  - 41XX series – Chromium-Molybdenum
    - Cr - 0.50, 0.80, 0.95
    - Mo - 0.12, 0.20, 0.30
  - 43XX series – Nickel-Chromium-Molybdenum
    - Ni – 1.82
    - Cr - 0.50, 0.80,
    - Mo – 0.2
- Alloys are heat-treated to the specific strength and hardness levels necessary for the particular application.

Drilling Metallurgy

- BOP Body – Cast or forged 4130 or 4140
  - » Shear rams – 4340, 4140, 2-1/4 Cr -1 Mo
- BOP components – 4130, 4140, 8660, 8630, 2-1/4-1Mo
  - – Martensitic SS – 410, F6NM, CA6NM
- Tool joints – 4135-4140
- Drill string subs – 4140, 4130, 4340, 4240H
- Drilling jars, stabilizers, core barrels – 4140, 4145, 4340
- Drill collars – 4153, 4140, 4145
- Non-magnetic drill collars – Monel K500, 15-15LC
- Drill pipe – 1040, 1045 + additions for fine grain

Engineering Materials - Completion

- Carbon & Low Alloy Steels – most applications require YS 60 – 125 ksi
- Aluminum alloys – 30 – 40 ksi YS
- Stainless Steels – 60 – 110 ksi YS
- Precipitation Hardened SS – 170 ksi YS
- Nickel Base Alloys – 110 – 140 ksi YS
- Titanium Alloys – 110 – 140 ksi YS

Sour Service Requirements

- NACE MR0175/ISO 15156:
  - Is applicable to materials used for – Drilling, well construction, and well servicing
  - Permitted exclusions –
    - Equipment only exposed to drilling fluids of controlled composition
    - Drill bits
    - Blowout preventer (BOP) shear blades
    - Drilling riser system
    - Work strings
    - Wireline and wireline equipment
    - Surface and intermediate casing

Material Limits - Temperature

Versus Temperature, we consider -

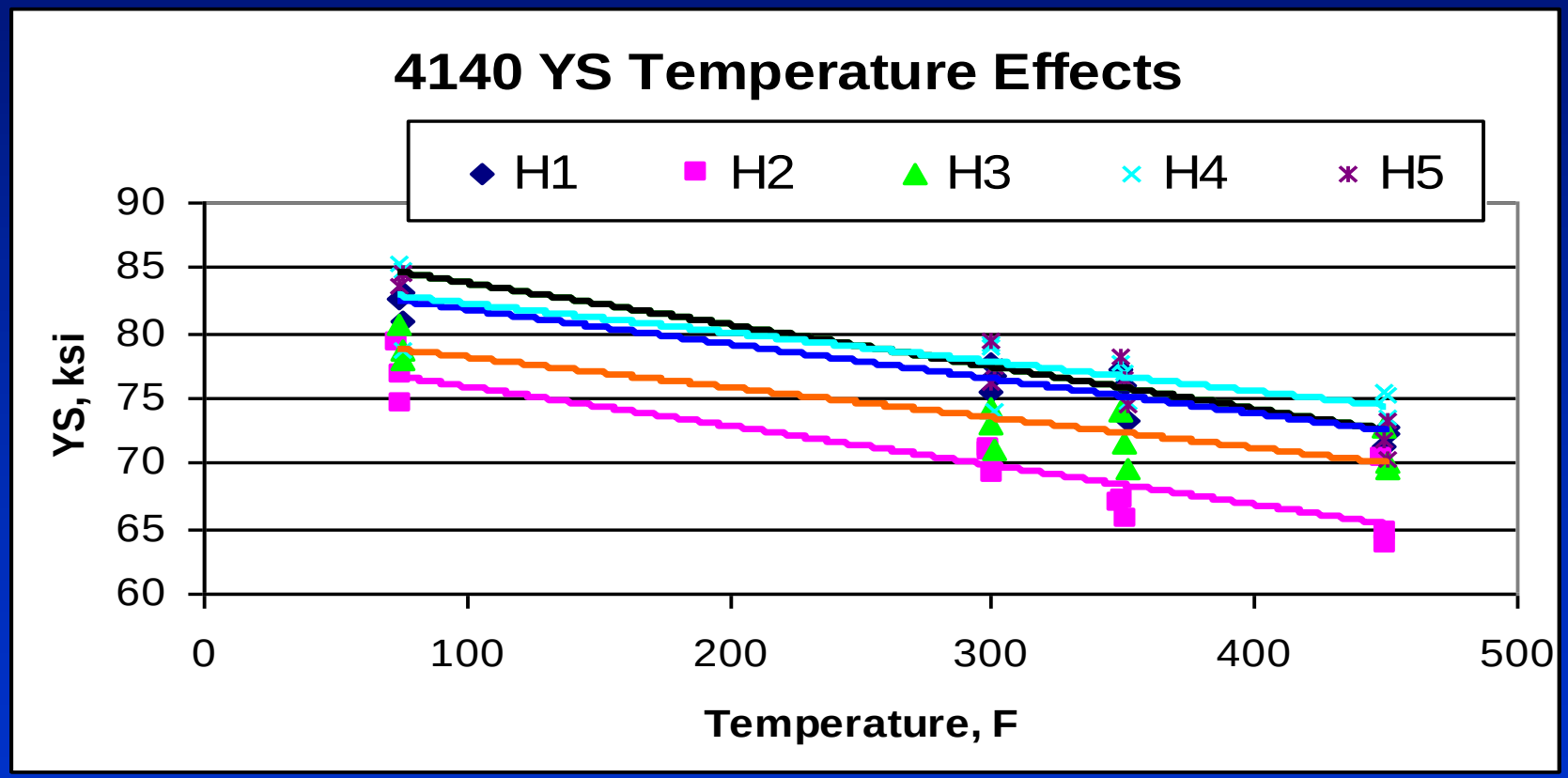
- Strength
- Corrosion Resistance
- Environmental Cracking Resistance (H_2S & CO_2)

Material Limits - Pressure

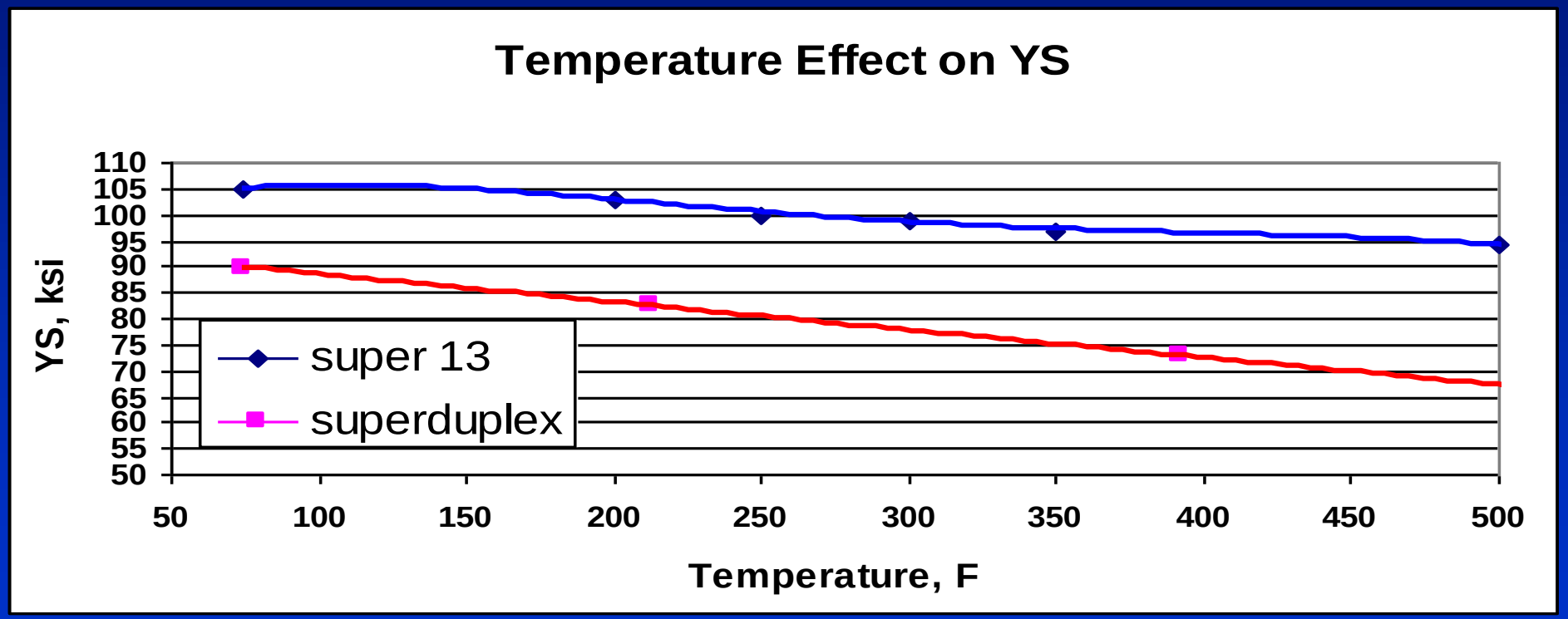
Higher Pressure Equates to Higher Stress, we consider -

- Cracking Resistance (Threshold Stress)
- Notch Sensitivity/Brittle Fracture
- Fatigue Resistance
- Elastic Movement

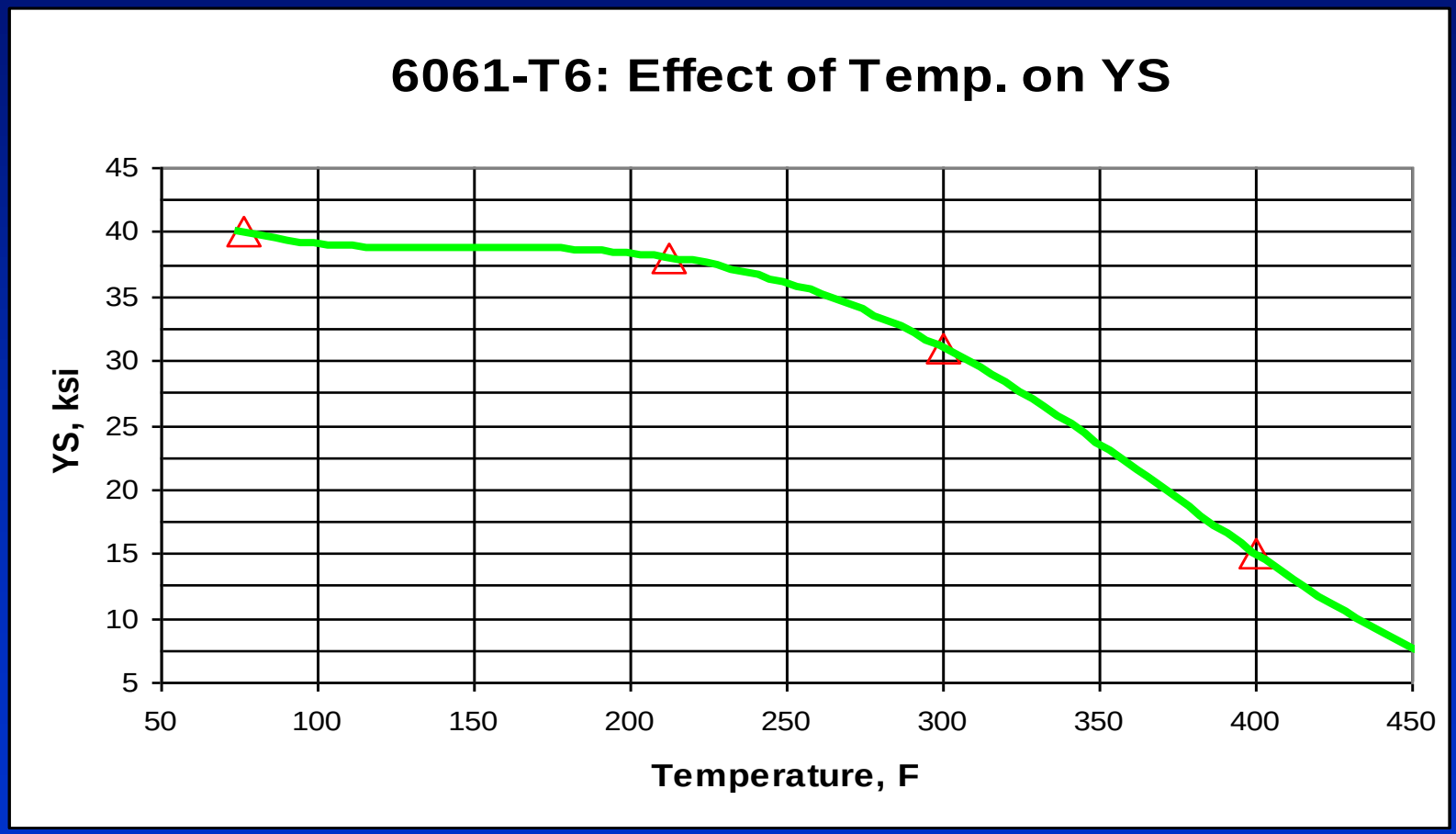
Steel – YS versus Temperature



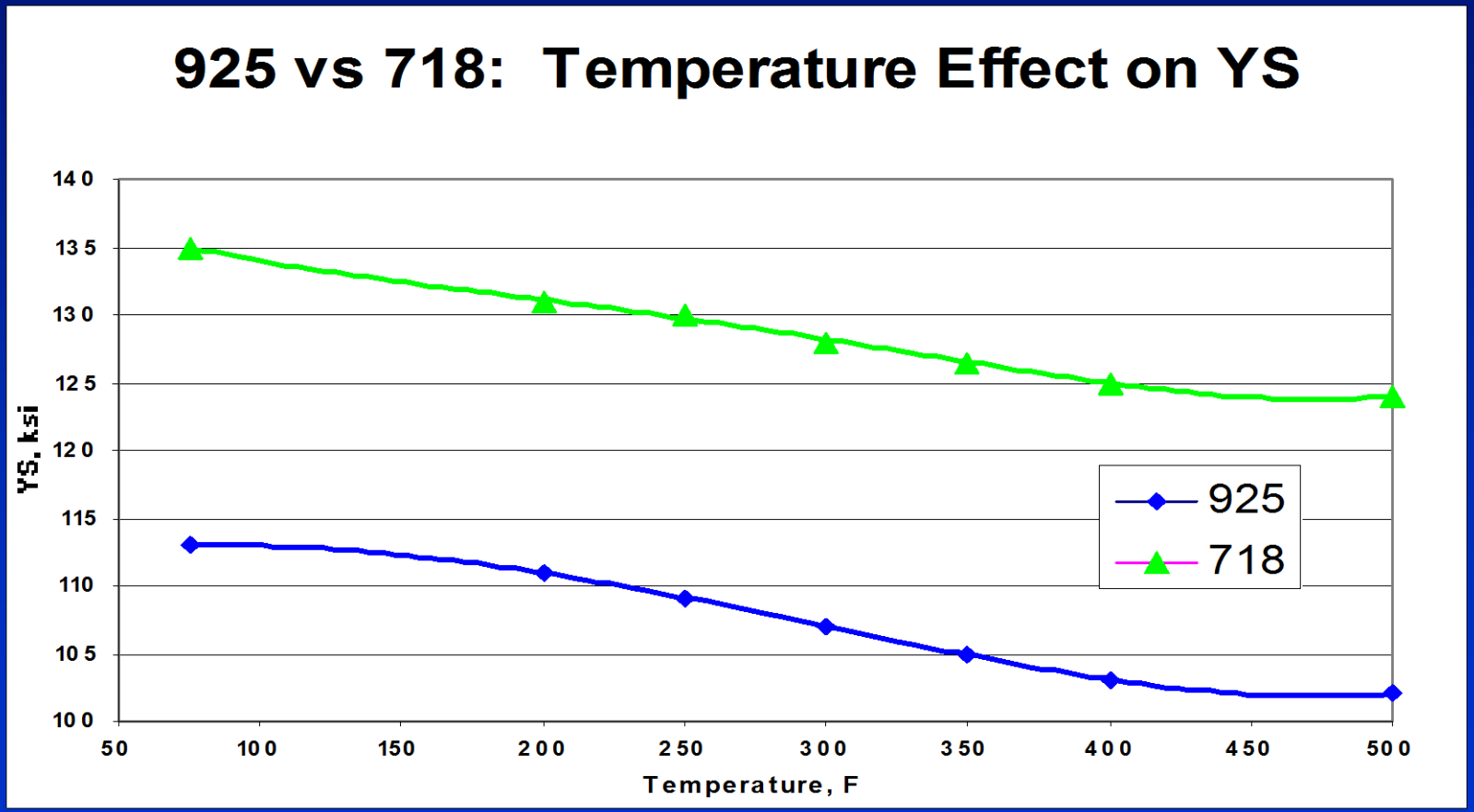
Stainless Steels – YS versus Temperature



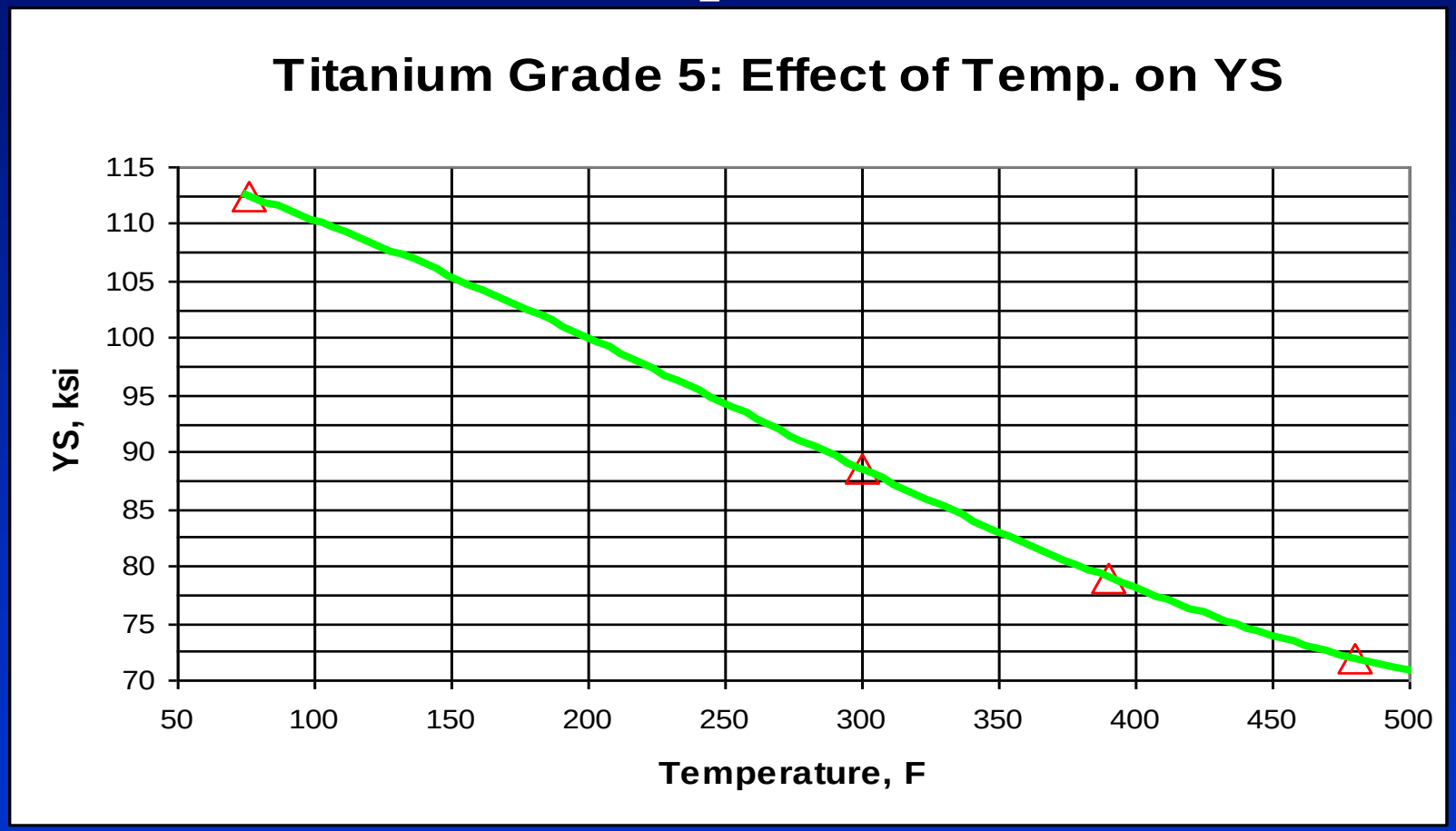
Aluminum Base Alloys – YS versus Temperature



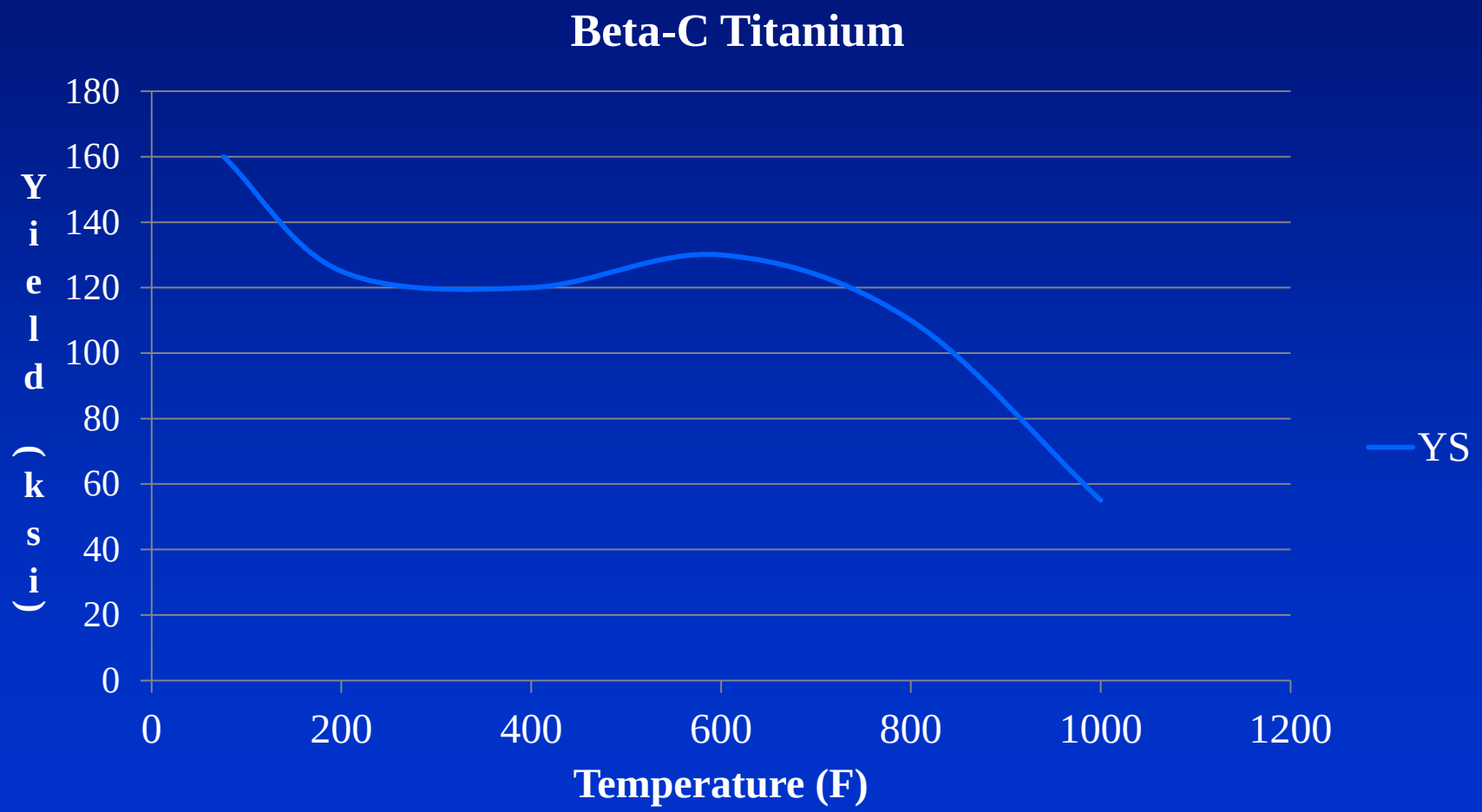
Nickel Base Alloys – YS versus Temperature



Titanium Base Alloys – YS versus Temperature



Titanium Base Alloys – YS versus Temperature

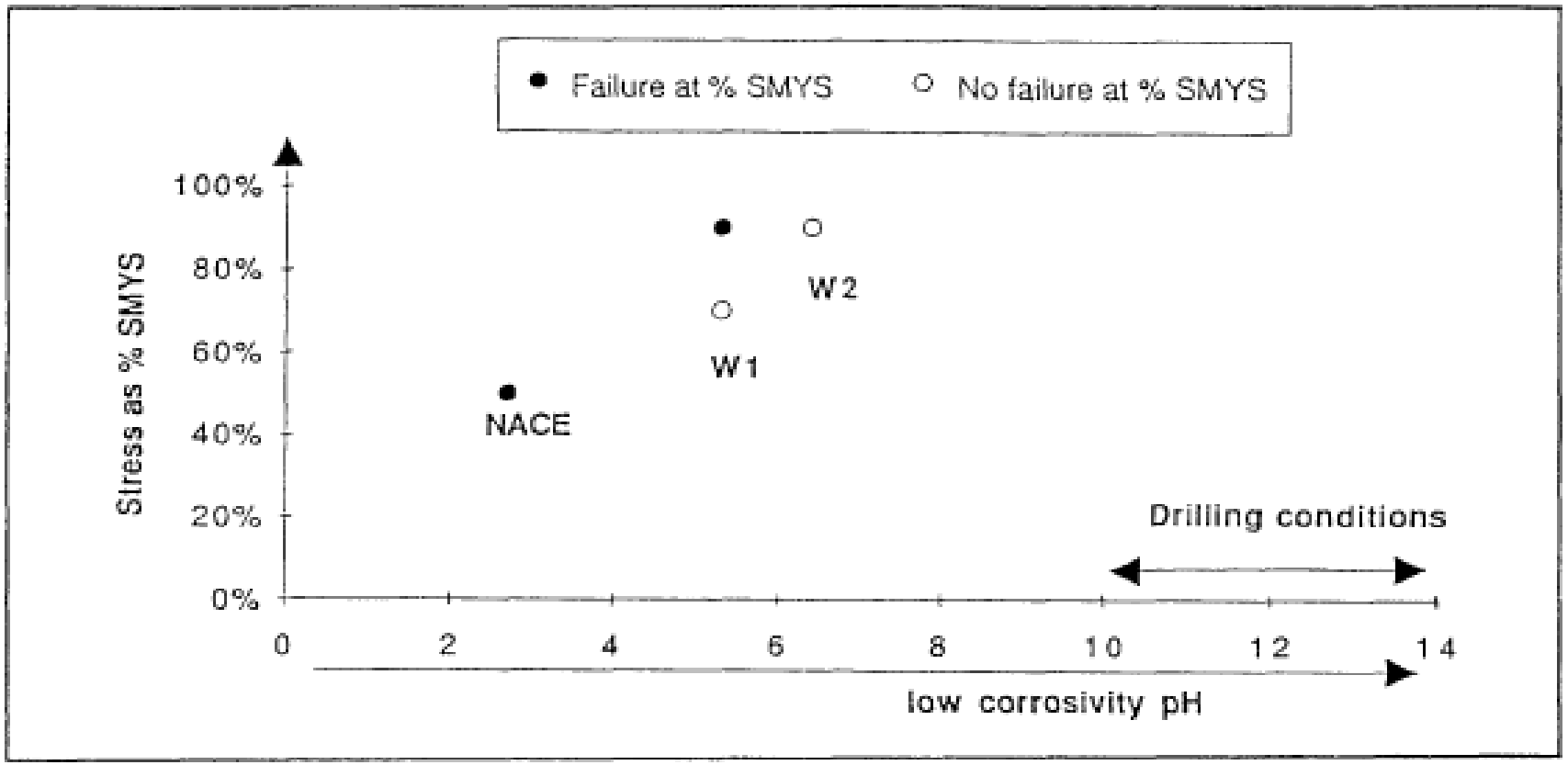


Limits – Pressure + Temperature

Both together have a synergistic effect on:

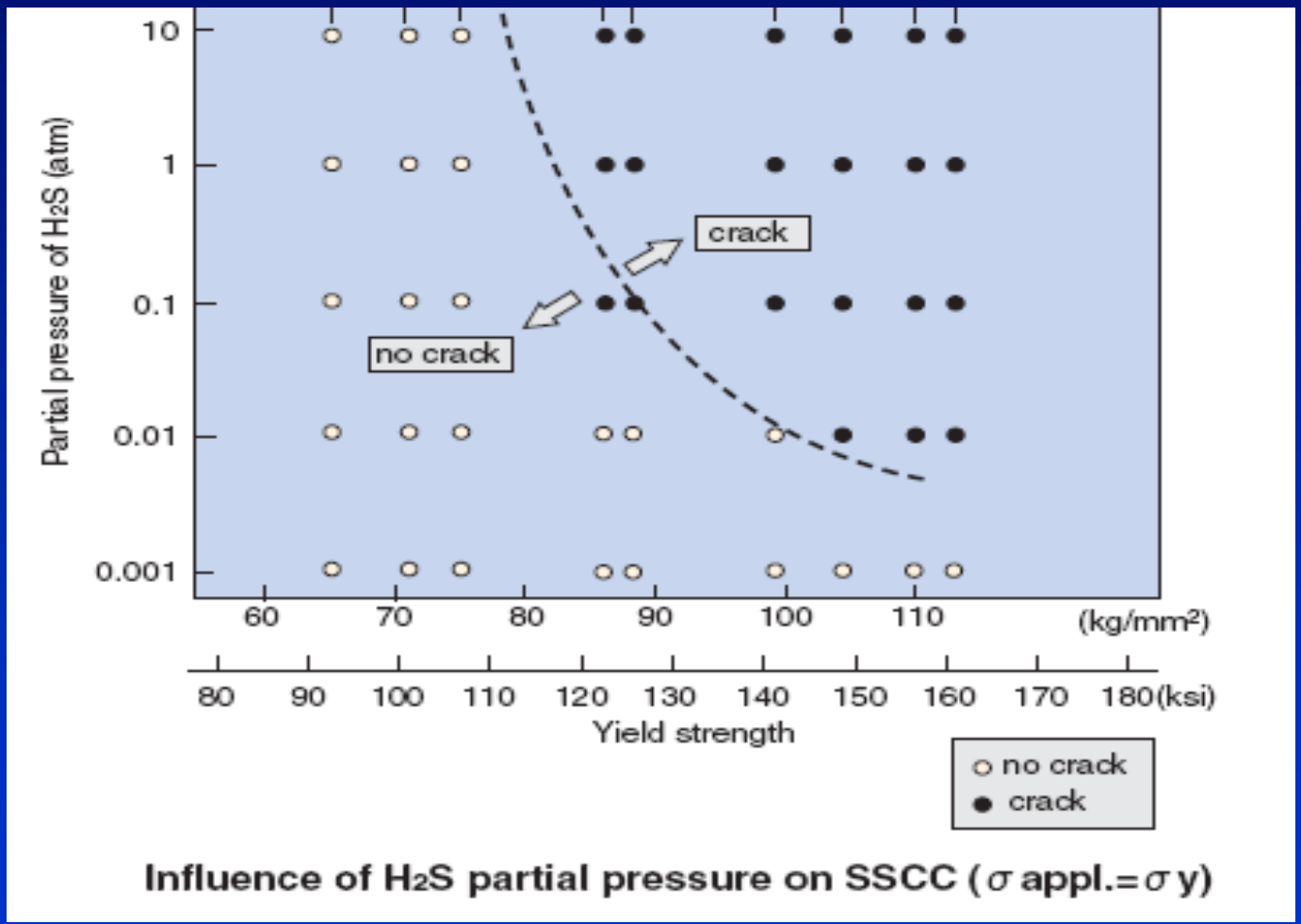
- Cracking Resistance
- Fatigue Resistance
- Elastic Movement
- Strength Requirements

Drilling – Stress & Cracking



Drill Pipe Cracking in H2S

Steel Cracking – YS Level



Influence of H_2S partial pressure on SSCC (σ appl.$=\sigma$ y)

Steel Cracking – YS Level

For steels selected & processed for resistance to cracking in H_2S:

- 135 ksi actual = 0.5 psi @ 75% SMYS
- 125 ksi actual = 15 psi @ 80% SMYS
- 115 ksi actual = 15 psi @ 100% SMYS

Nickel Steels H_2S Cracking

- For nickel based alloys cracking sensitivity increases with increased temperature:

Nickel Based (cold worked)

Alloy 825 -- 300 F Max (test) – group of 3 Mo grades

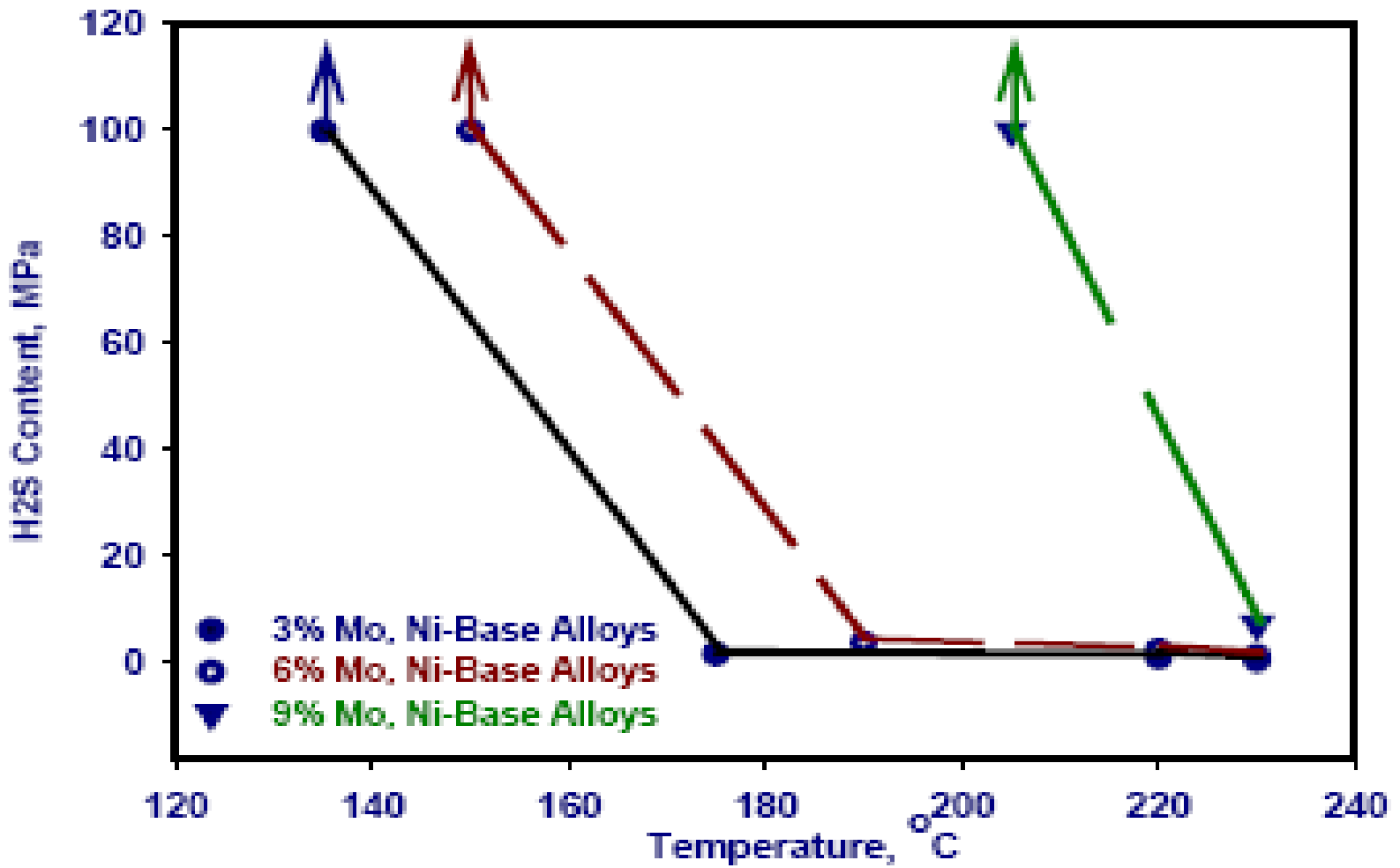
254 SMO, 904L, AL6XN --- Max 350F (test) 6 mo

Alloys G-2, 625, C-22 – 400 F (test) – 8- 12Mo

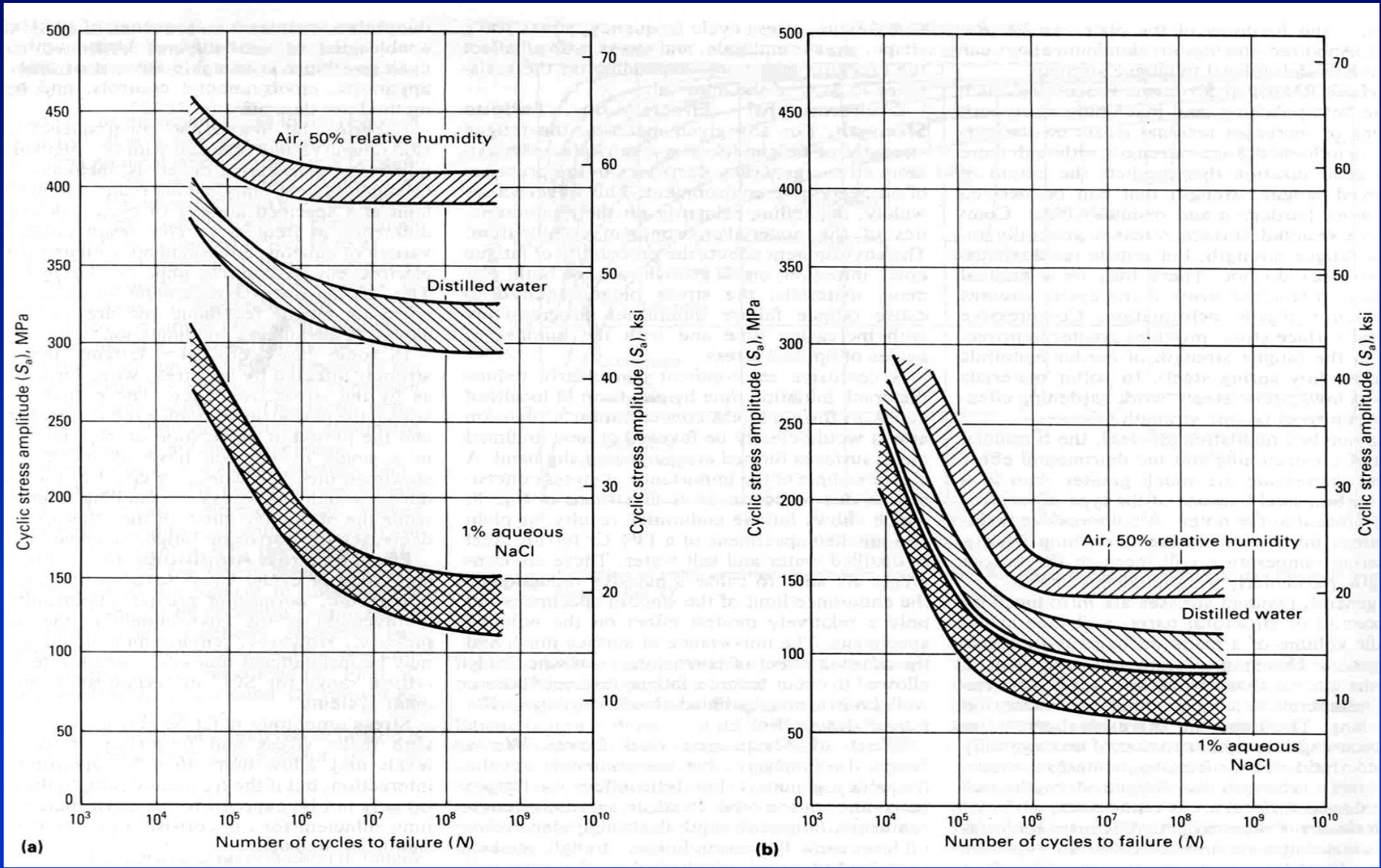
Alloy C-276 – 450 F+ 15-17 Mo (test)

Free sulfur – all bets are off.

Cracking Resistance - Temperature



Fatigue Resistance



HPHT Challenges

- Common Engineering Materials
- Material Application Envelopes

Problem Areas

- Sealing mechanisms
- Safety Factors
- Chemical Inhibition
- New Materials and at Higher strengths
- Material Substitutions (& Qualification)
- Code Development
- Design verification issues
- Greater metal cross sections
- Inspection criteria/Maximum flaw size
- Investment and Cost

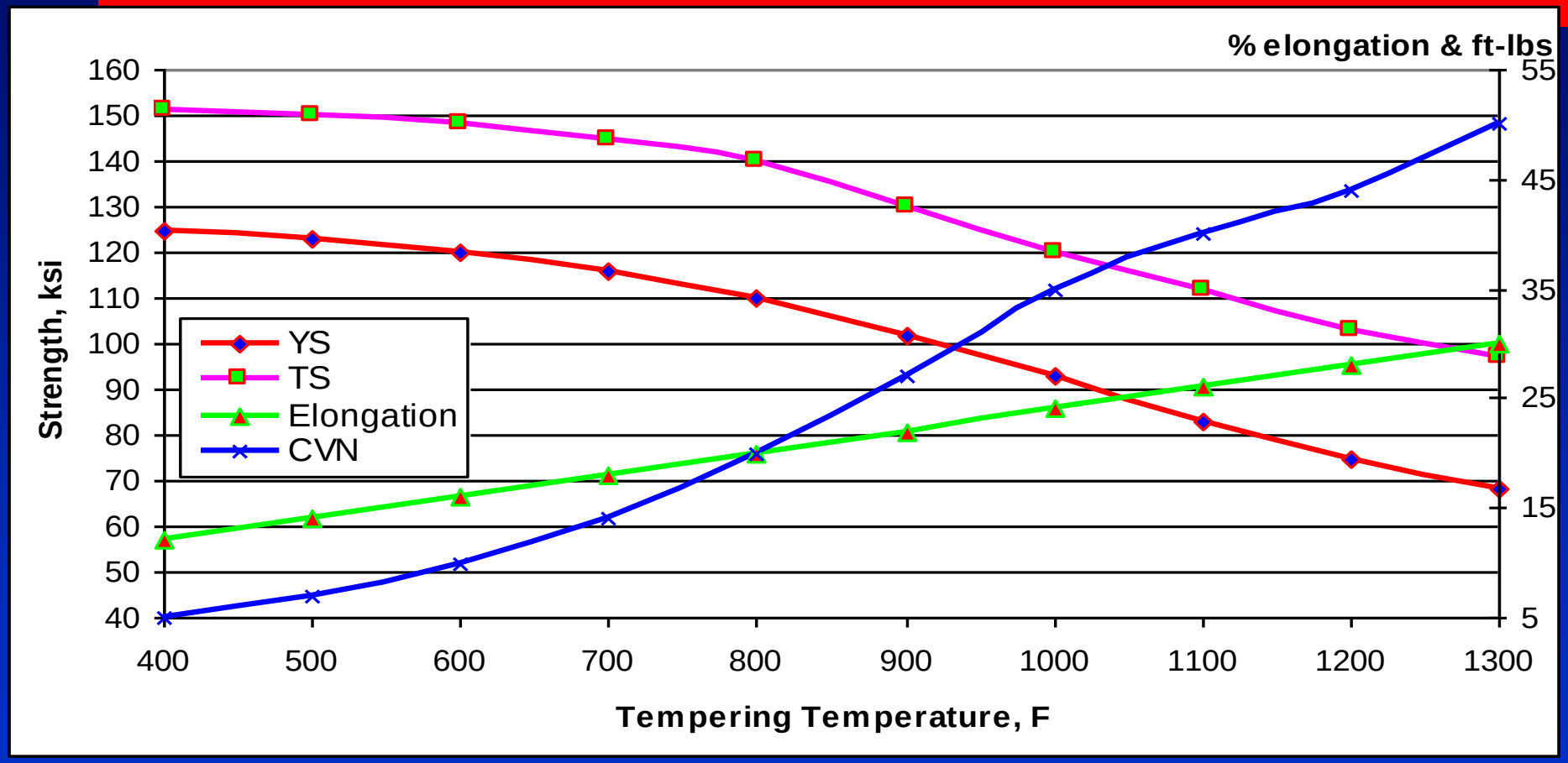
Potential Solutions

Materials

- Higher strength H_2S resistant steels
- Higher alloy nickel base alloys
- Titanium base alloys
- Composites
- Composite Elastomeric Materials

Questions?

Engineering Materials - Completion



Relationship between Q&T Steel Properties