SCH - CICC Fatigue Life Considerations

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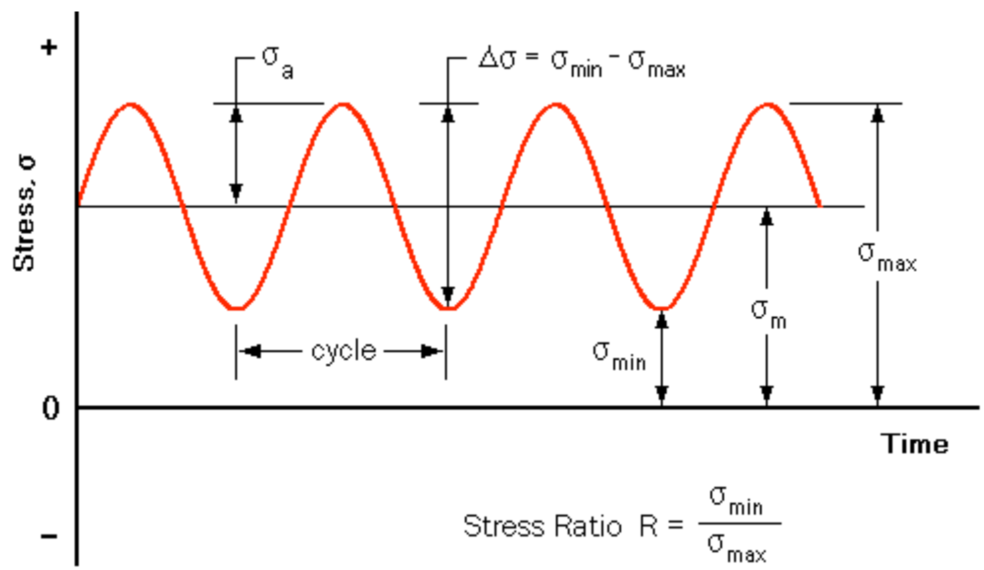


Background:

• The primary structure (the 316LN conduit) of the magnet will undergo maximum of 20,000 full-field sweeps over a 20 yr life

• Design codes with safety factors are applied to ensure safe/reliable operation of the magnets.

• A comprehensive material and weld qualification program is being conducted to confirm and verify compliance with design code fatigue requirements.

Outline:

• Fatigue design philosophy
• Traditional S-n fatigue design
• Dynamic Fracture Mechanics for fatigue design
• 4K FCGR properties of 316LN
• Allowable flaw size
• NDT methods and R&D
•.Summary

Fatigue Design Philosophy

Traditional Fatigue Design - Check design values with respect to the conduit material's fatigue life data (S-n Curve). Individually satisfy the appropriate **Safety Factors**;

Design Life = 20 X service life
= 20 X 20,000 = 400,000 cycles
Stress = 2 X Service Stress
= 2 X 368 MPa = 736 MPa

Fracture Mechanics Fatigue Design - assume a pre-existing flaw and apply fracture mechanics to calculate stress intensity factor (K). Evaluate the magnets fatigue life with respect to conduit materials fatigue crack growth rate (FCGR) properties and allowable flaw size.

Safety Factors

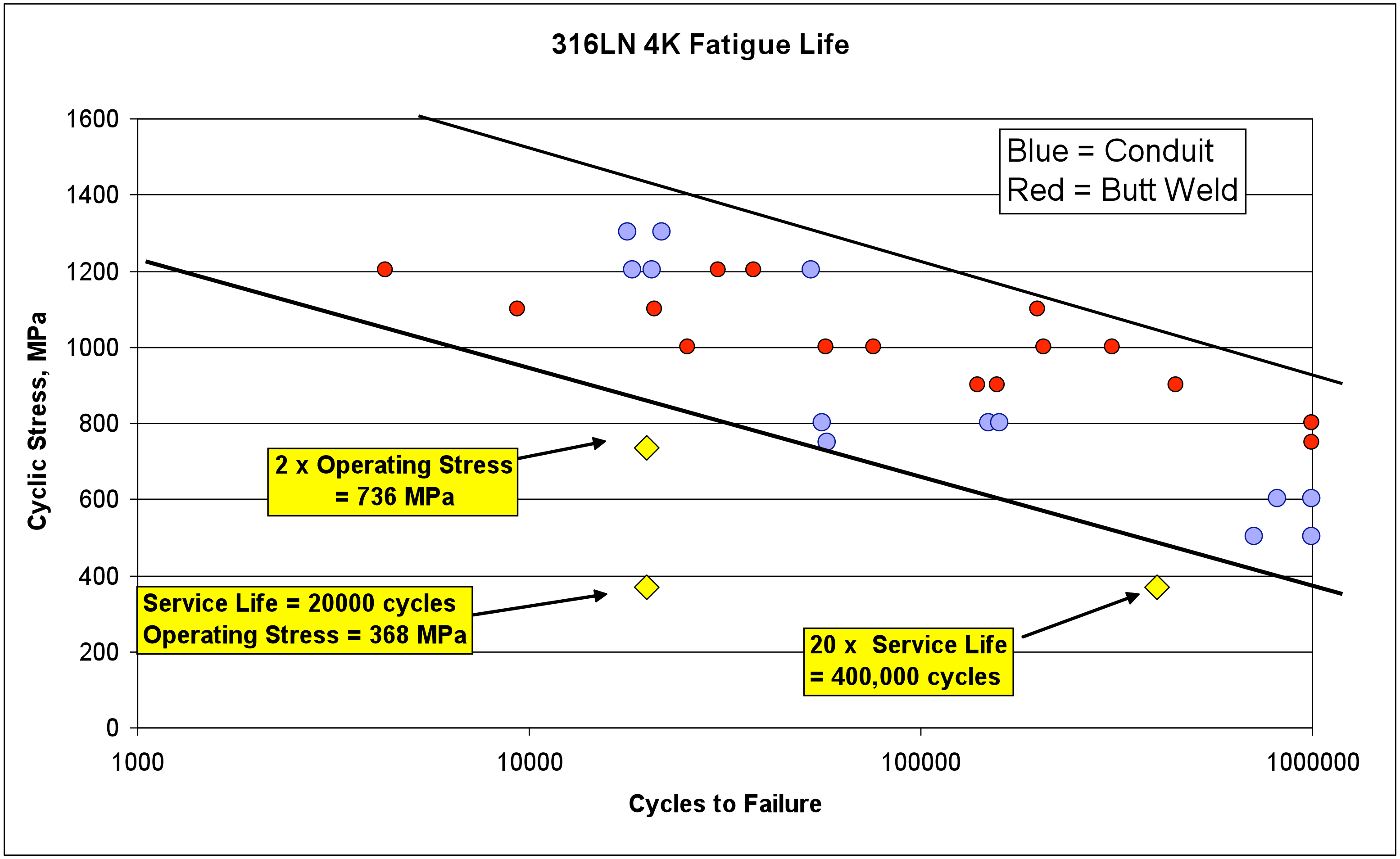
Design Life;
(FIRE) 4 X 20,000 = 80,000 cycles
(ITER CS) 2 X 20,000 = 40,000 cycles
Flaw Detection = ½ allowable flaw

Traditional Fatigue Design

Individually satisfy each of the **Safety Factors**;

20 X Design Life

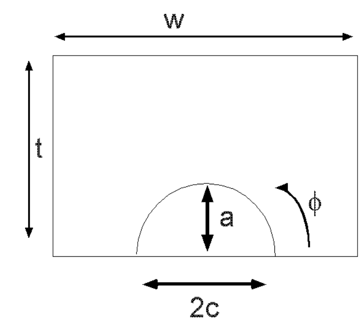
2 X Design Stress

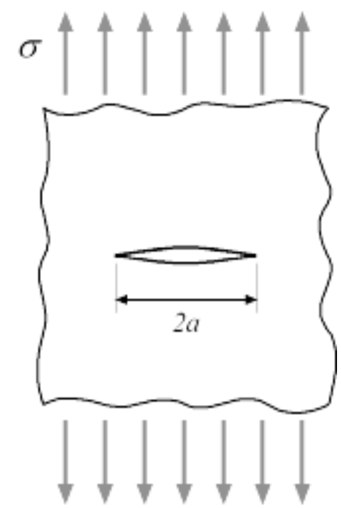


Fracture Mechanics Fatigue Design – a more conservative design approach, acknowledges material imperfections can create localized stress intensity that may generate and drive fatigue cracks

- Assume a pre-existing flaw
- Calculate a stress intensity factor (K).
- Evaluate the design life with respect to 316LN FCGR properties

Assume semi-elliptical flaw in infinite width plate





$K = \sigma ((\pi a)^{0.5})$ MPa*m^0.5

Modify eqn. for crack shape factor

$K = F \sigma ((\pi a / Q^{0.5})$ MPa*m^0.5

Insert cyclic stress range to calculate ΔK, the fatigue stress intensity range.

Example:
if Stress cycle = 0 to 368 MPa
and flaw size, a = 0.25 mm
Then;
ΔK = 9 MPa*m^0.5

Fatigue Crack Growth Rate Testing: Performed over a range of applied stress intensity factors to determine the Stage II (Paris regime) FCGR parameters (ASTM E647 test procedures).

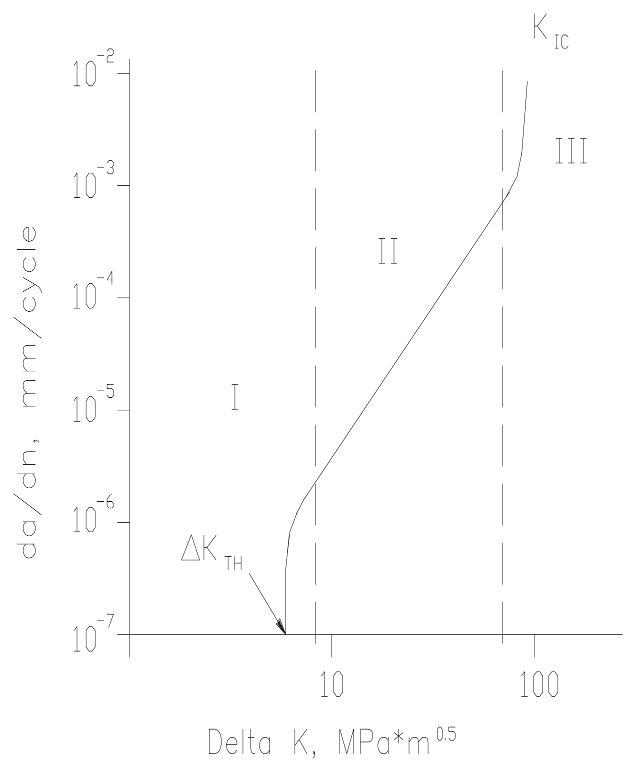
- Paris Law:
  $da/dn = C * \Delta K^m$

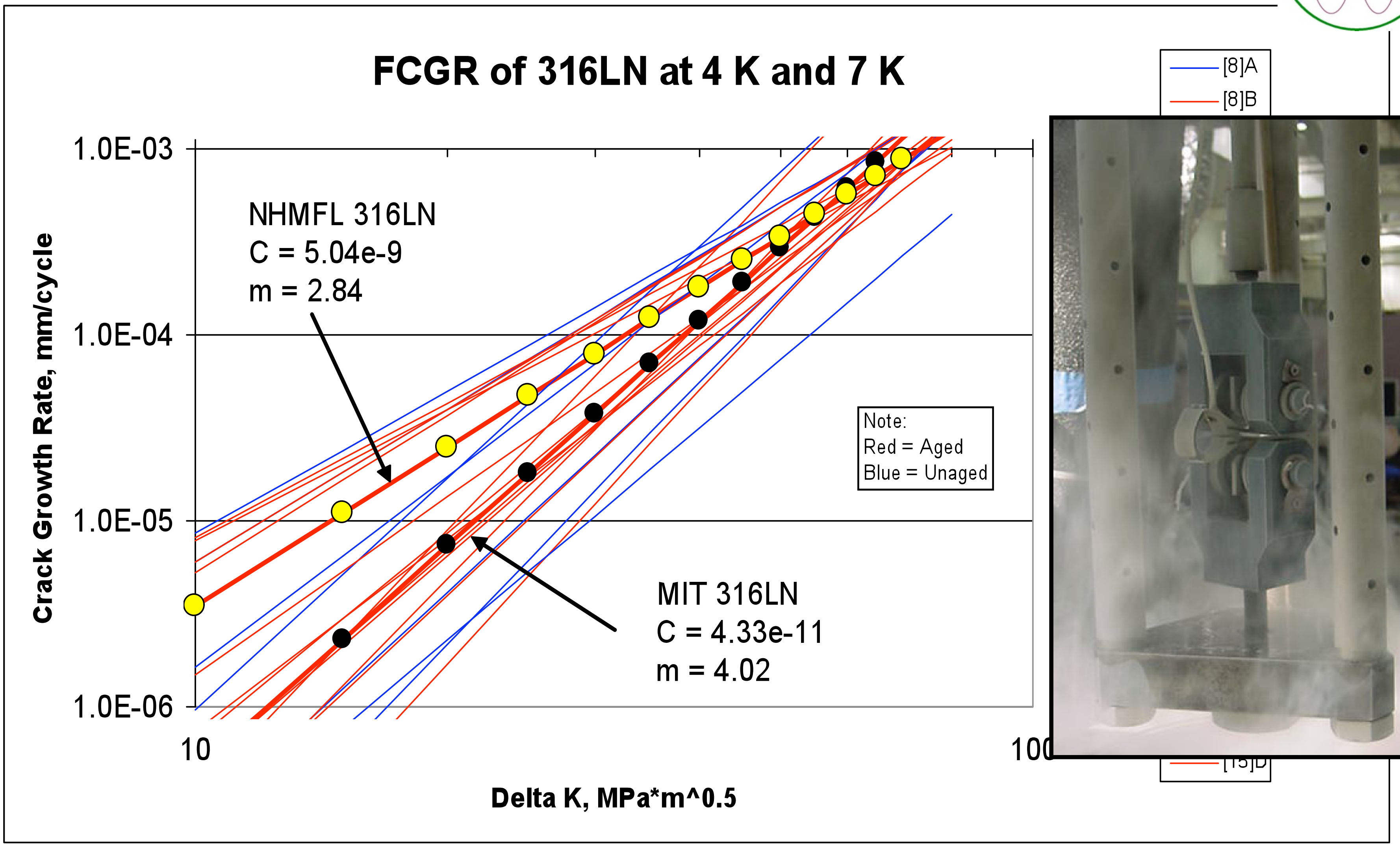
Where:

da/dn = crack growth rate (mm/cycle)

C and m = material constants

ΔK = stress intensity range




FCGR of 316LN at 4 K and 7 K
Crack Growth Rate, mm/cycle
1.0E-03
1.0E-04
1.0E-05
1.0E-06
10
100
Delta K, MPa*m^0.5
NHMFL 316LN
C = 5.04e-9
m = 2.84
MIT 316LN
C = 4.33e-11
m = 4.02
Note:
Red = Aged
Blue = Unaged
[8]A
[8]B

Implications of Flaw Size and FCGR on the Fatigue Life

Given:
Applied Stress = 380 MPa
Wall = 2.4 mm
Alloy, 316LN Modified
Paris Constants:
C = 5.04e-9
m = 2.84

Safety Factor on Cycles	**Fatigue Cycle Requirement** **cycles**	**Allowable Flaw Size** **mm**	**Starting Δ K** **MPa*m^0.5**	**Required Flaw Detection, 1/2 Allowable** **mm**	**Δ K at 1/2 allowable flaw** **MPa*m^0.5**	**Comment**
1	20,000	0.69	19	0.345	13	No problem with flaw detection
2	40,000	0.41	14	0.205	10	Required = Anticipated resolution of flaw detection system
4	80,000	0.198	10	0.099	7	Can't detect, Note; requirement creates ΔK less < material threshold

The *allowable flaw size* and conduit *FCGR* properties are critical. The issue is being addressed on two fronts.

1. Ensuring reliable-reproducible welding

- A proven capability at NHMFL.
- Procedures developed produce high quality automated TIG welds.
- Mechanical and metallurgical inspection have been used to optimize procedure.

- Ongoing - quantify characteristic flaw size w/ industry standard x-ray inspection techniques to develop statistical database.
(estimated inspection measurement resolution = 2% wall = 0.05 mm).

316LN Research Welds

2. Evaluation of on-line NDT inspection capabilities.

- Research state-of-art NDT capabilities for CICC application.
  NDT Options;
  - X-Ray
  - Ultrasonic
  - Eddy Current
- Solicited experts in ea field and engaged in application specific R&D.
- Preliminary evaluations of NDT limitations and usefulness.

- Future work- Evaluate options and select based on cost and capability.