AC7101/3 Fatigue Testing

Fatigue Training for Auditors

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Agenda

- Fatigue Properties
- Reason for Testing
- The Different Types of Fatigue
- Specifications for Fatigue Tests
- Equipment for Fatigue Tests
- Specimens for Fatigue Tests
- Auditing Fatigue Tests

Fatigue Properties

The main properties obtained are:

- Fatigue Life
- Fatigue Crack Growth Rate
- Threshold Fatigue Crack Growth Stress Intensity Factor Range

Reason for Testing

- Liberty ships (1941 – 1945)

- Aloha Airlines Flight 243 (1988)

Reason for Testing

1. Integrity
   How large of a crack can you tolerate? (Fracture Toughness)

2. Durability
   How long will it take? (*Fatigue & Fatigue Crack Growth*)

3. Confidence
   How sure are you? (Testing & Statistics)

4. Cost
   Will your company profit?

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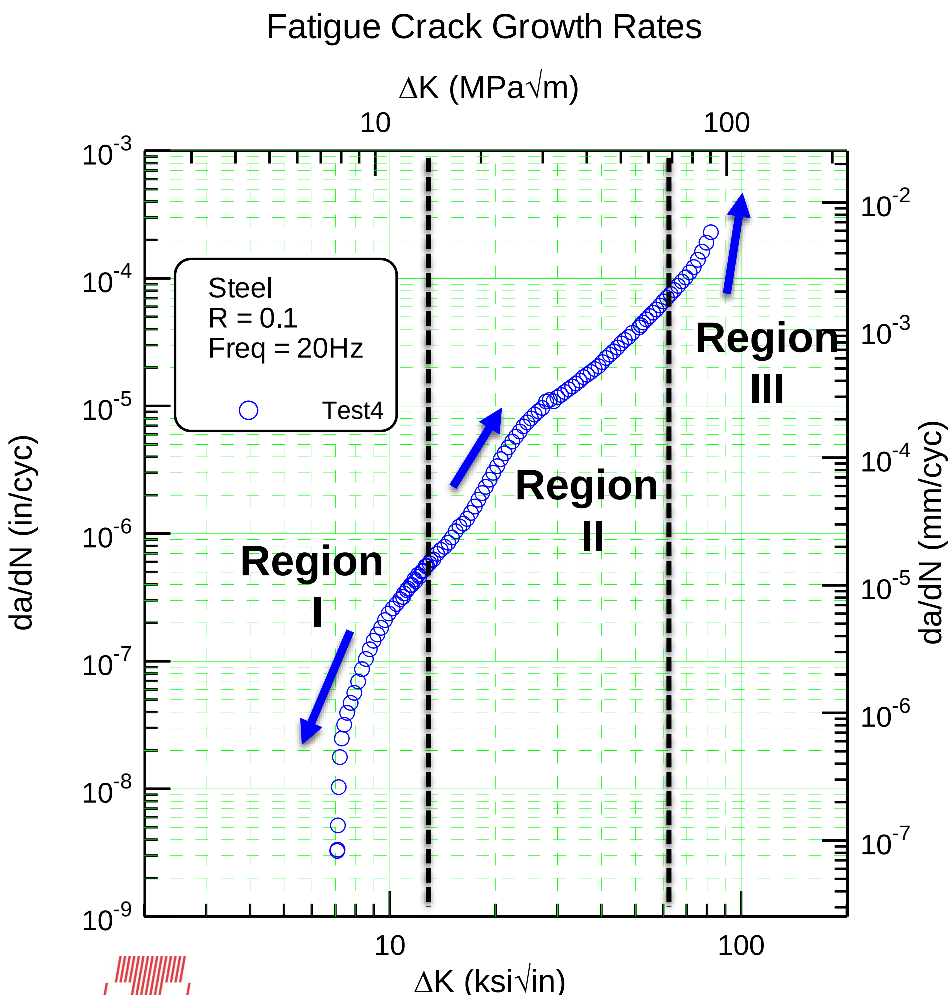
Types of Fatigue: High Cycle Fatigue (HCF), Code O

- Failure that occurs in structures subjected to alternating stresses.
- Failure may occur at a stress level considerably lower than the tensile or yield strength for a static load.
- Usually occurs after a lengthy period of repeated stress cycling.
- Tests are performed in load control.
- Cycles to failure typically in the 1E7 to 1E8 range.
- Simplest of the fatigue test types.

Types of Fatigue: Low Cycle Fatigue (LCF), Code Y

- Tests are performed in strain control.
- Cycles to failure typically in the 1E3 to 1E4 range.
- Tests are typically at elevated temperature.

Types of Fatigue: Crack Propagation (FCGR), Code XE



- ΔK is the driving force for fatigue crack growth
- Arbitrary regions I, II, and III can be defined
- Threshold (Region I) and upper end (Region II, III) are separate segments.
- The blue arrows in the graph depict the direction test data is measured

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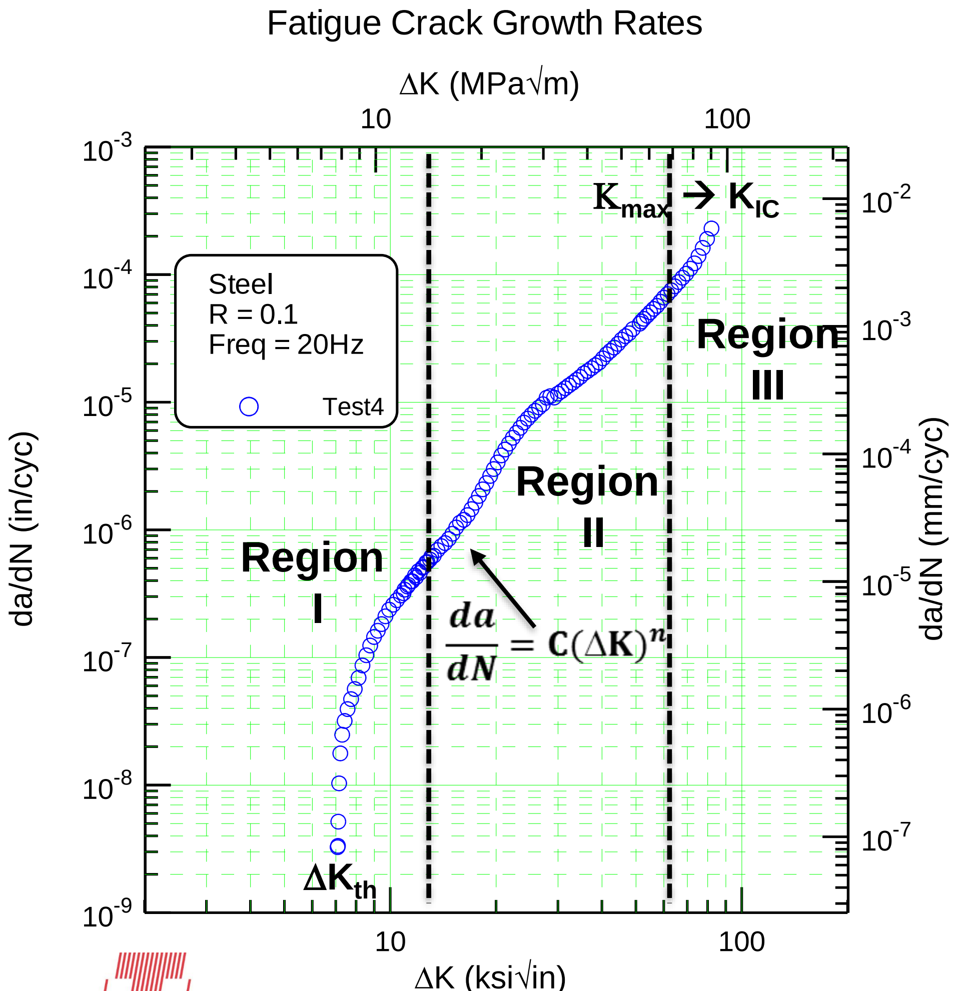
Types of Fatigue: Crack Propagation (FCGR), Code XE



- Region I: threshold (asymptote)
  - ΔK_{th} is crack growth threshold
- Region II: Paris Regime:

$$\frac{da}{dN} = C(\Delta K)^n$$

Linear

  - n = slope
  - C = intercept
- Region III: instability, $K_{max} \rightarrow K_{IC}$ (asymptote)

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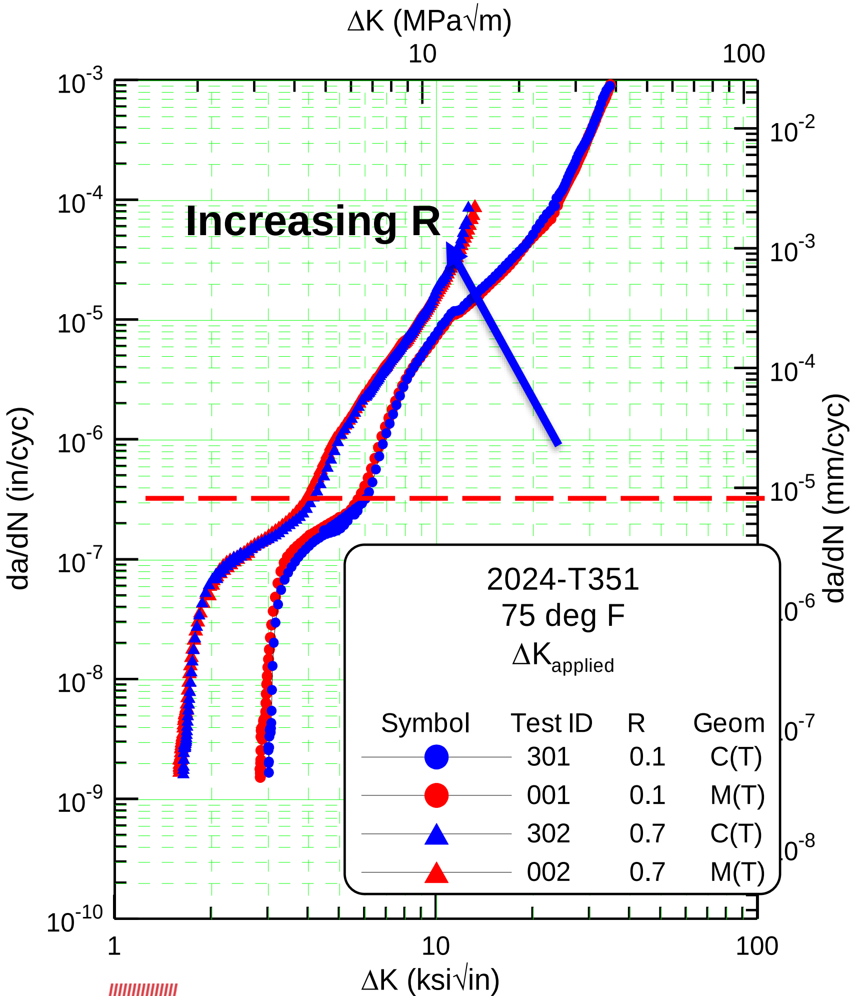
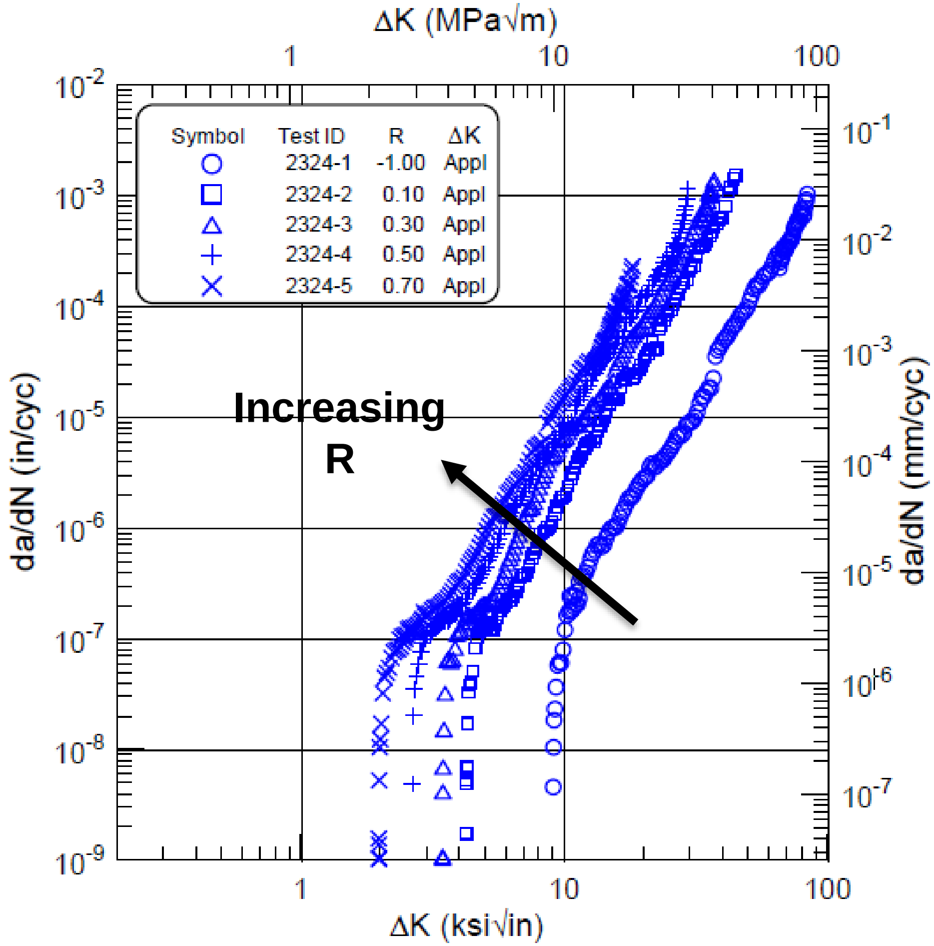
Load Ratio Effects



- Load Ratio $R = P_{max} / P_{min}$ or $R = K_{min} / K_{max}$
- Higher load ratio data is generally shifted up and to the left.
- M(T) and C(T) data is in good agreement at both load ratios.

Load Ratio Effects



- The spread in data with R cannot be easily modeled and is not well understood (must be tested.)
- Always need to know R when performing FCGR test.

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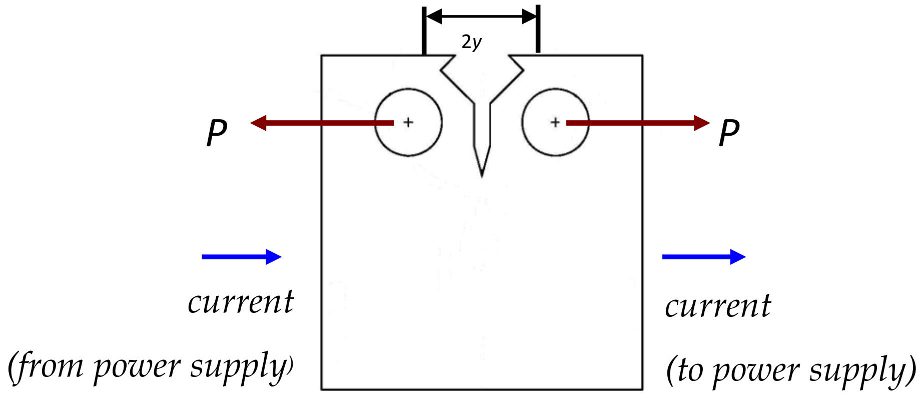
Crack Length Monitoring

- Two primary methods of measuring crack length are allowed by ASTM E647 and used:
  - Potential Difference (PD)
  - Compliance
- PD passes a current through the specimen and correlates the increase in voltage as measured across the crack to crack length.
- Compliance is the inverse of stiffness – closed-form equations are used to relate the increase in compliance with crack length for known specimen geometries.

Potential Difference (PD)

- Constant current is passed through the specimen, and voltage (PD) is monitored across the crack as the crack grows.



Johnson's Equation

$$V = \cosh^{-1}\left(\frac{\cosh(\pi y / 2W)}{\cos(\pi a / 2W)}\right)$$

- Provides the relationship between voltage and crack length (calibration).

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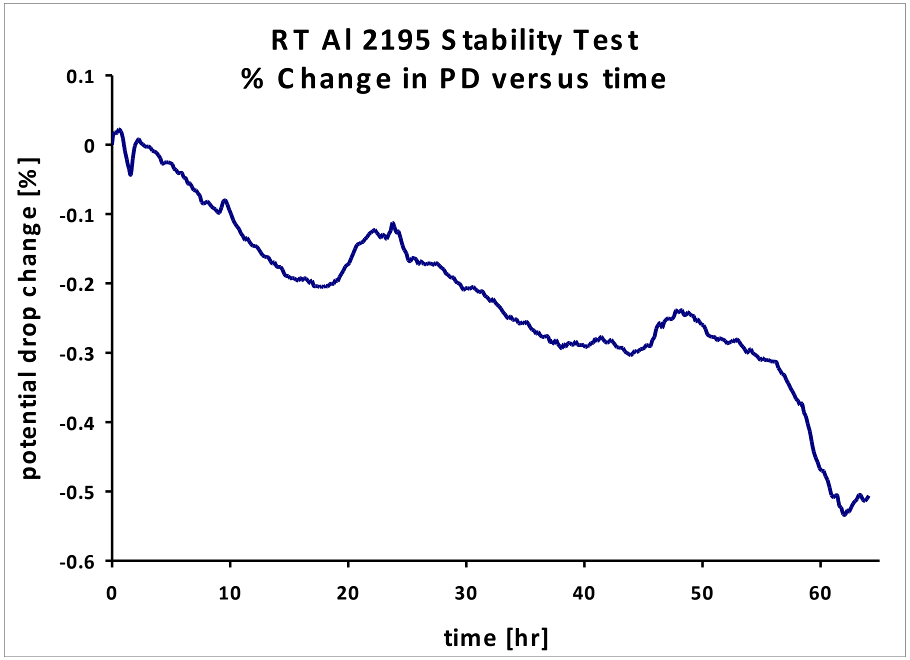
Potential Difference (PD)

- If current input is excessive or variable, specimen heating can occur.

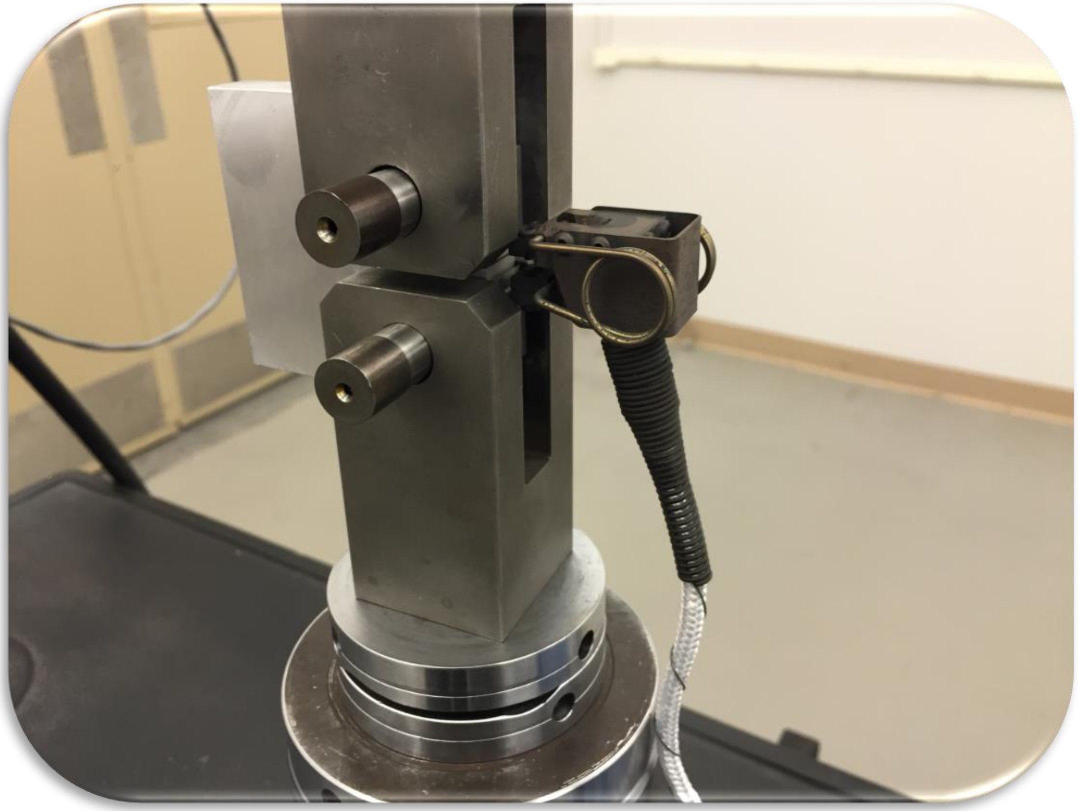
AC7101/3 Rev D § 12.12



- A stability test determines the amount of drift in the PD signal as a function of time, and whether this is acceptable.

AC7101/3 Rev D § 12.13

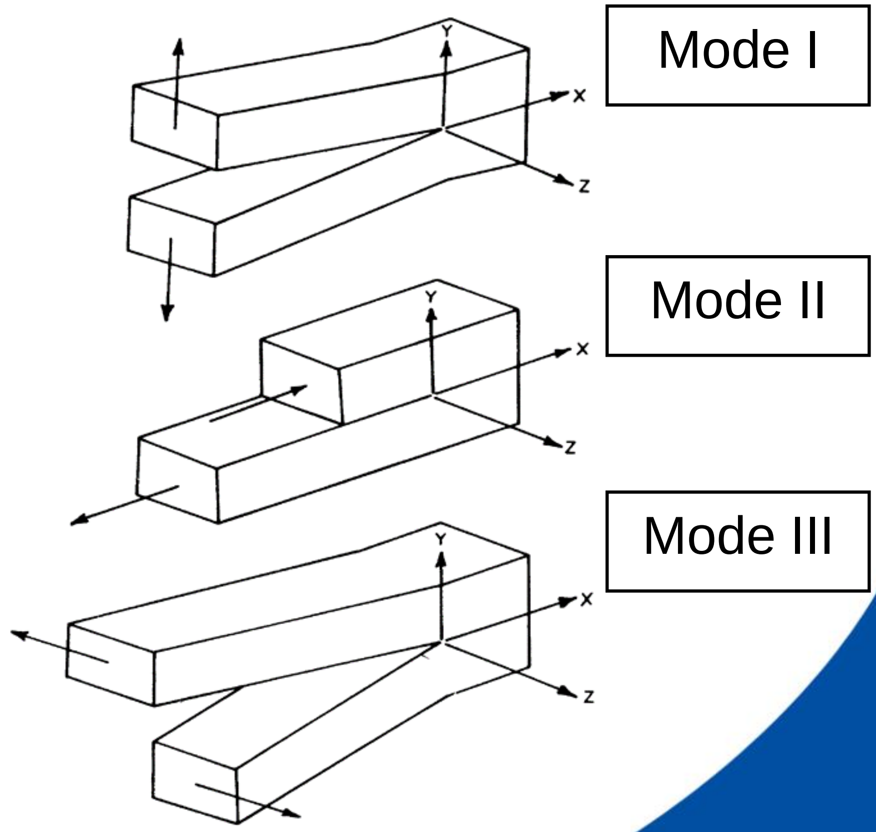
Compliance



- Clip gage is inserted between knife edges and measures crack mouth opening displacement (COD).

Types of Fatigue: Crack Propagation (FCGR), Code XE

- 3 separate loading modes
- Mode I is most dominant in practice.
- Cracks that start in Mode II and mode III often turn and grow in Mode I: exception is weak interfaces.
- Testing according to ASTM E647 is applicable to Mode I.



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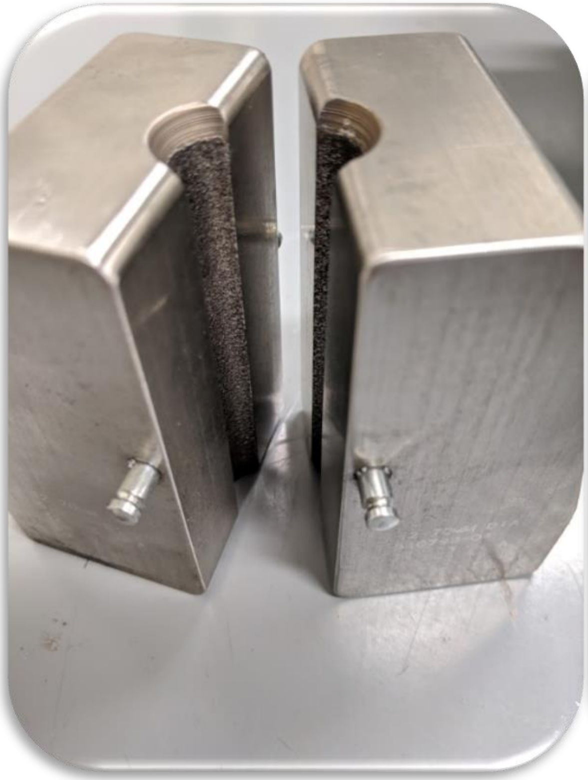
Specifications for Testing

- HCF: The mostly widely used specification is ASTM E466
- LCF: The mostly widely used specification is ASTM E606
- FCGR: The mostly widely used specification is ASTM E647

Topics Covered By ASTM E466, E606, E647

- Apparatus (Equipment)
- Test Specimens
- Procedures for Testing
- Reporting
- Interpretation of the Results

Equipment for HCF Testing



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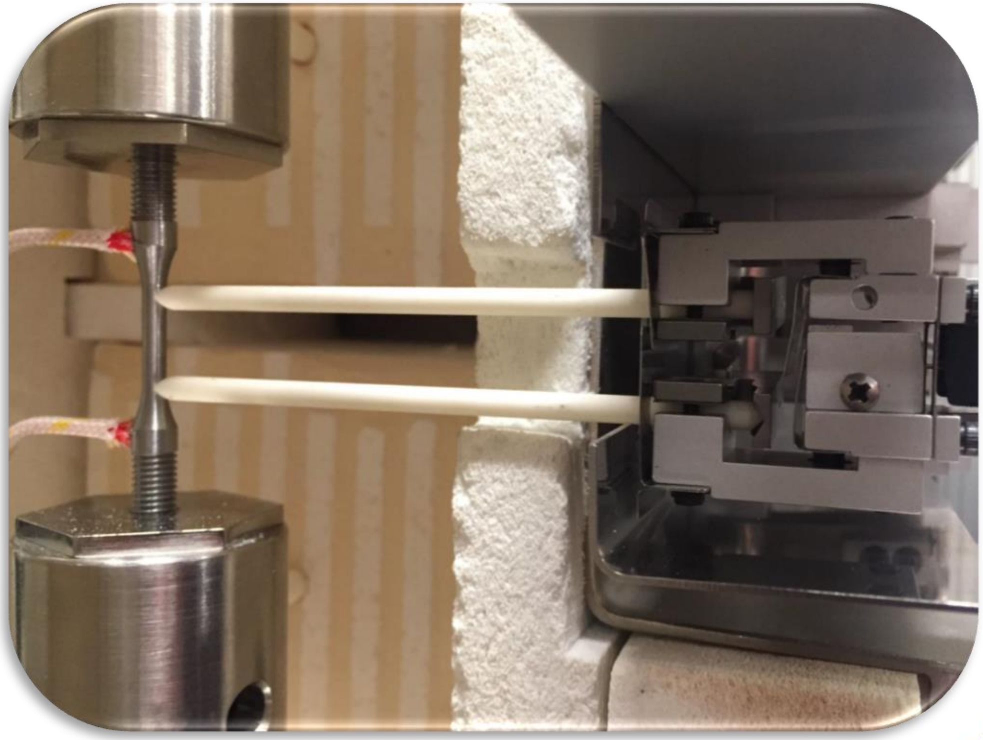
Equipment for LCF Testing



Equipment for FCGR Testing

Testing Machines

Column (x2)

Crosshead

Alignment Fixture

Load Cell

Test Specimen

Grips (x2)

Grip Controls

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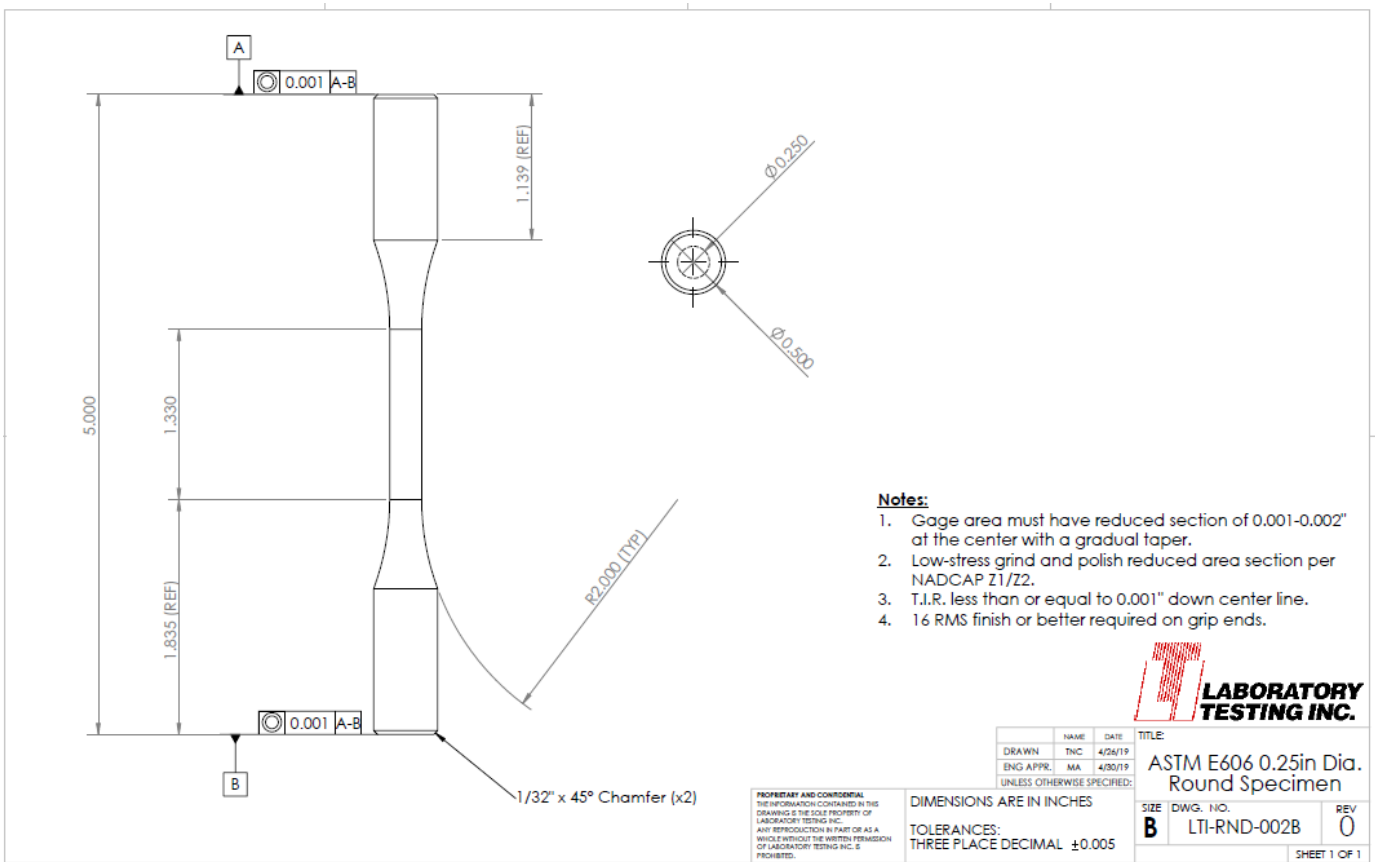
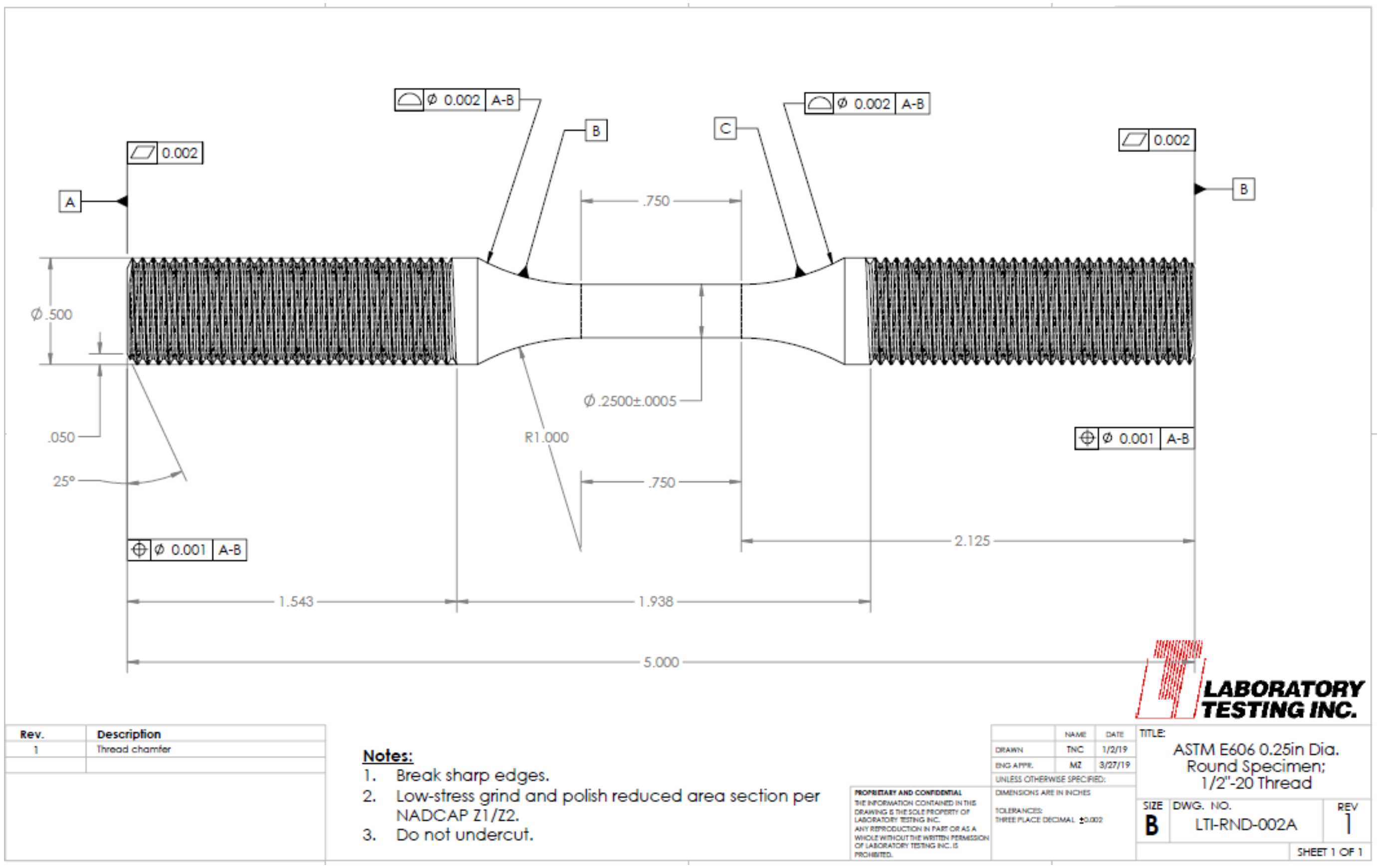
Testing Machines

Typical HCF Specimens



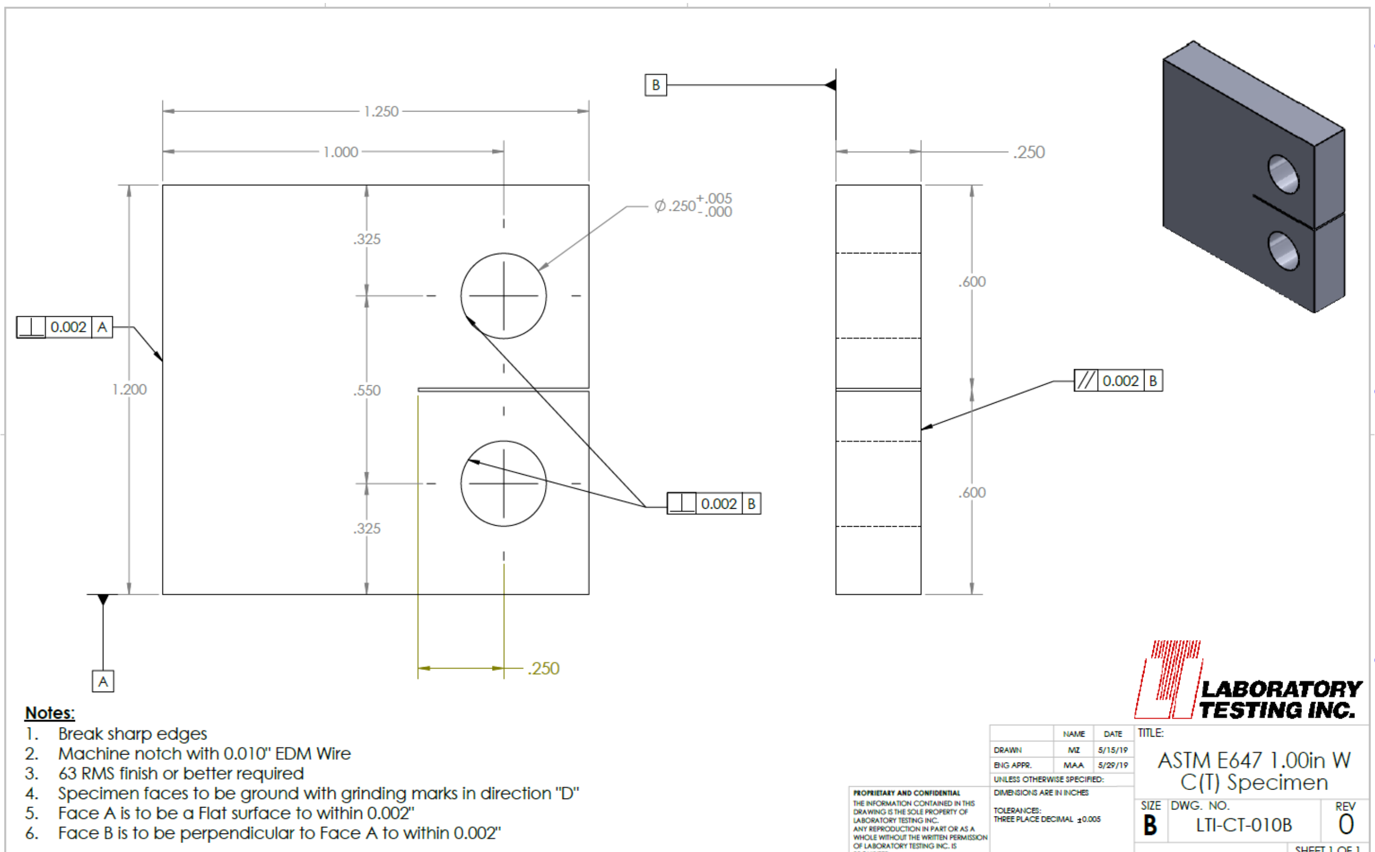
- Ends can be threaded or smooth.
- Can be notched or smooth.
- Can also test flats.

Typical LCF Specimens



- Ends can be threaded or smooth.

Typical FCGR Specimens



C(T) specimens are the most common.

Other common geometries include: M(T) SEN(T), Kb Bar

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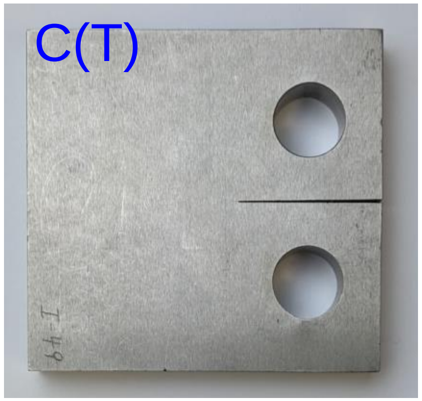
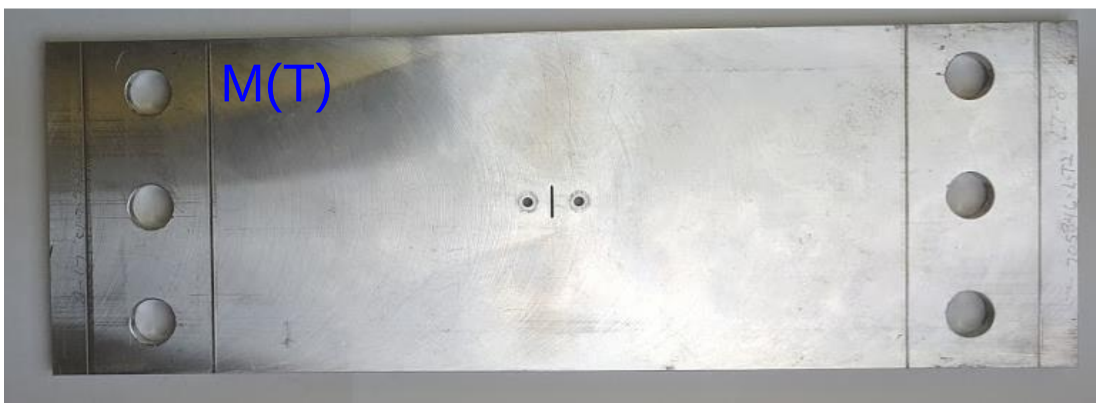
Typical FCGR Specimens





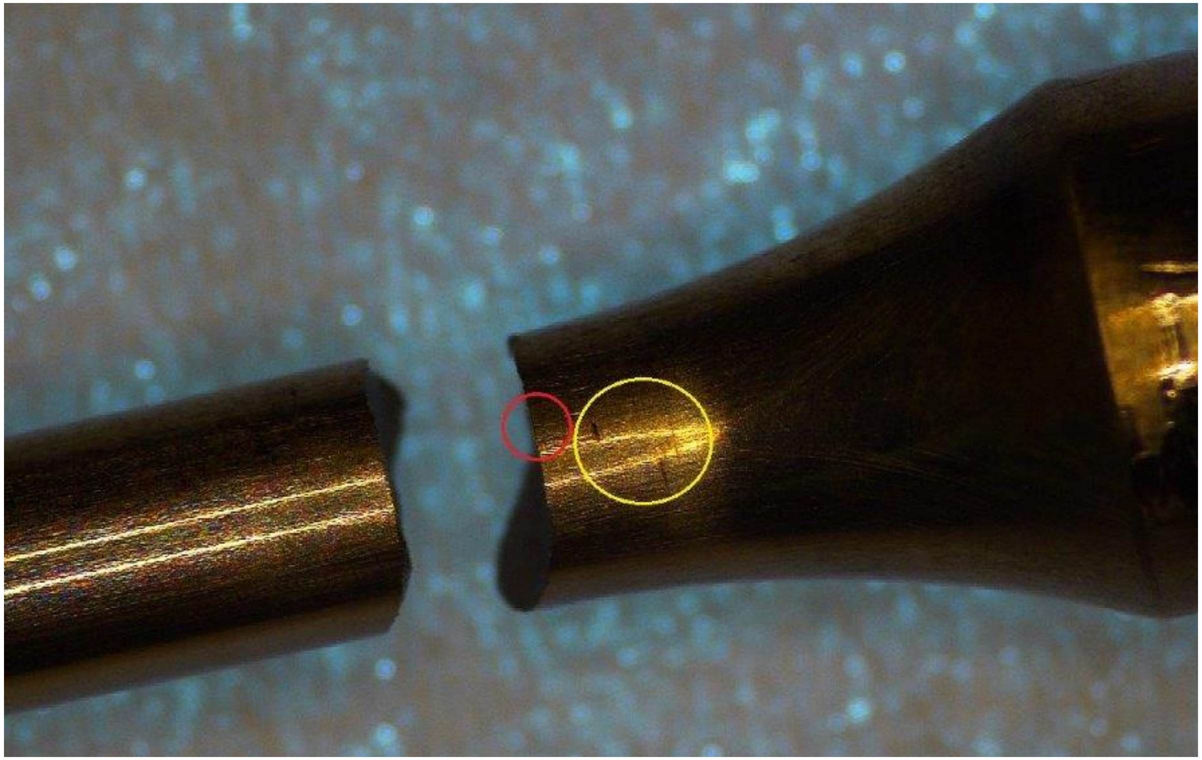
HCF, LCF, FCGR Testing Specimen Preparation

- Refer to Nadcap MTL checklist AC 7101/7
  - The objective of specimen preparation is to eliminate any effects of specimen preparation on the properties resulting from the test:
    - Absence of distortion of specimen dimensions
    - Absence of physical damage (e.g. cracks, tears, scratches)
    - Absence of residual stresses (tensile or compressive)
    - Absence of metallurgical damage (e.g. local overheating from abusive grinding or machining)
  - Inspection / acceptance of specimens
    - Each specimen is dimensionally inspected prior to forwarding to the testing laboratory.
  - Specimen preparation and equipment consistency is emphasized; fatigue results can have scatter

Auditing HCF Testing

- Failure in threads is possible – not necessarily a test lab issue.
- Alignment is critical for HCF testing (should be verified).
- Specimen heating should be measured.
- Specimens may be low stress ground and polished (AC7101/7).
- Specimens should be inspected for scratches or defects prior to testing.

Auditing HCF Testing



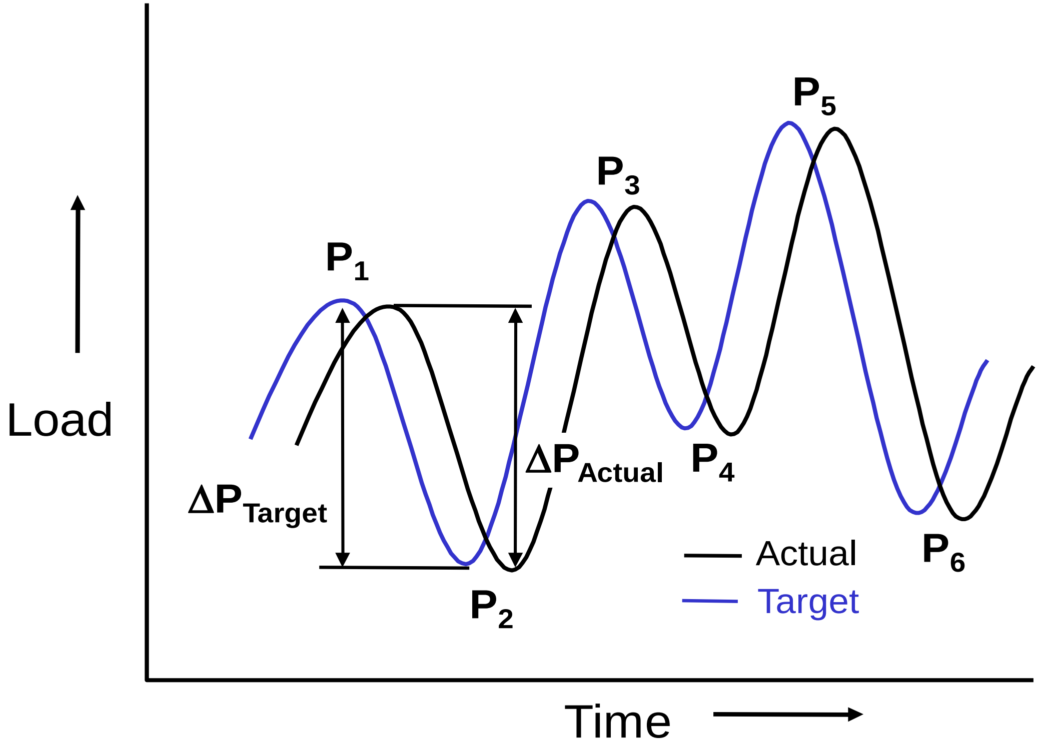
AC7101/3 Rev D § 8.10

- Surface irregularities recorded prior to test.
- Irregularities usually recorded on test cert (not required in § 8.12)

Auditing LCF Testing

- Failure in threads is possible – not necessarily a test lab issue.
- Alignment is critical for LCF testing (should be verified).
- Much lower frequencies – specimen heating not typically an issue.
- Specimens may be low stress ground and polished.
- Specimens should be inspected for scratches or defects prior to testing.
- Noise from extensometers and other equipment a possible issue.

Auditing FCGR Testing



- If you verify the load peaks P, you also verify the K peaks as K is directly proportional to load!

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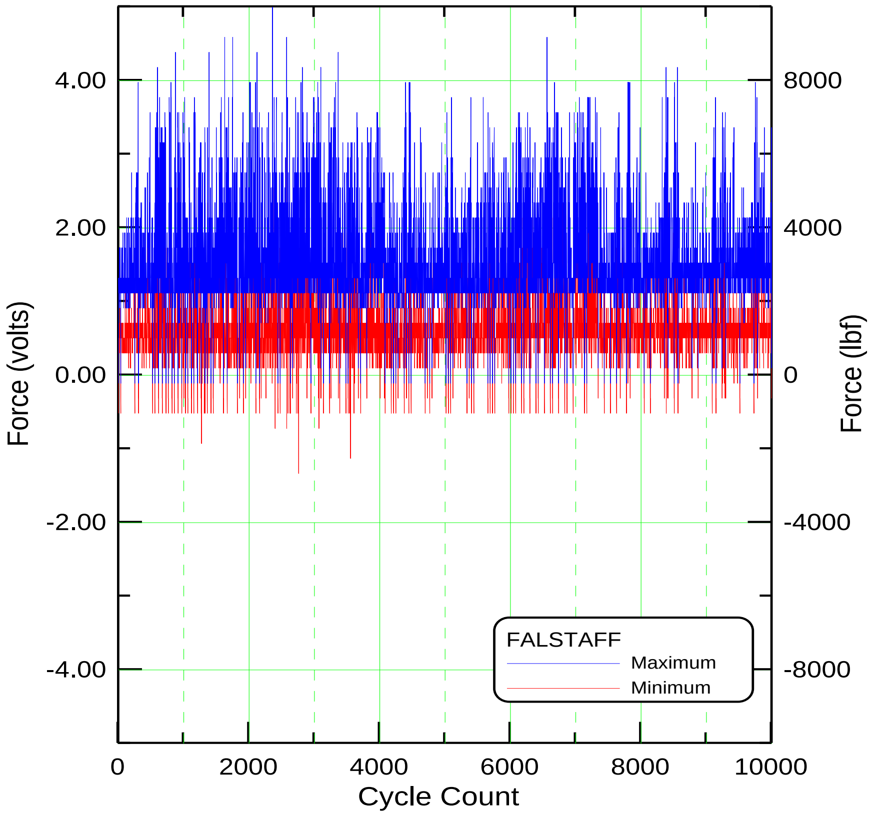
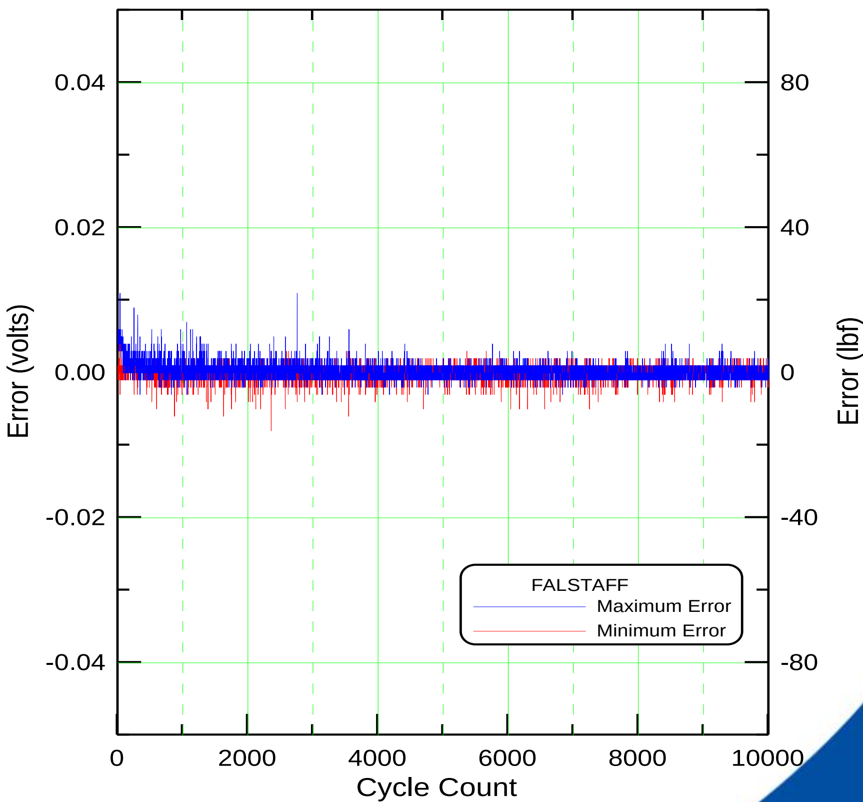
Auditing FCGR Testing



Actual Endpoints



Endpoint Errors

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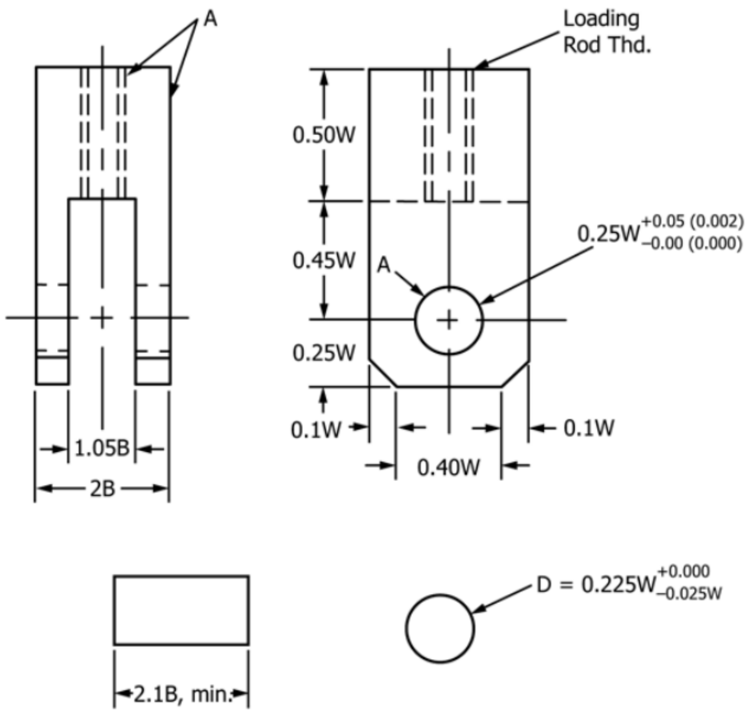
Auditing FCGR Testing



NOTE 1—Dimensions are in millimeters (inches).

A-surfaces shall be perpendicular and parallel as applicable to within ± 0.05 mm (0.002 in.) TIR.

Surface finish of holes and loading pins shall be 0.8 (32) or better.

FIG. A1.2 Clevis and Pin Assembly for Gripping C(T) Specimens

- Clevises for FCGR tests per ASTM E647 show specific tolerances on the clevis hole and pin diameter.
- These dimensions are critical for linearity of the load-displacement signal but are rarely audited.

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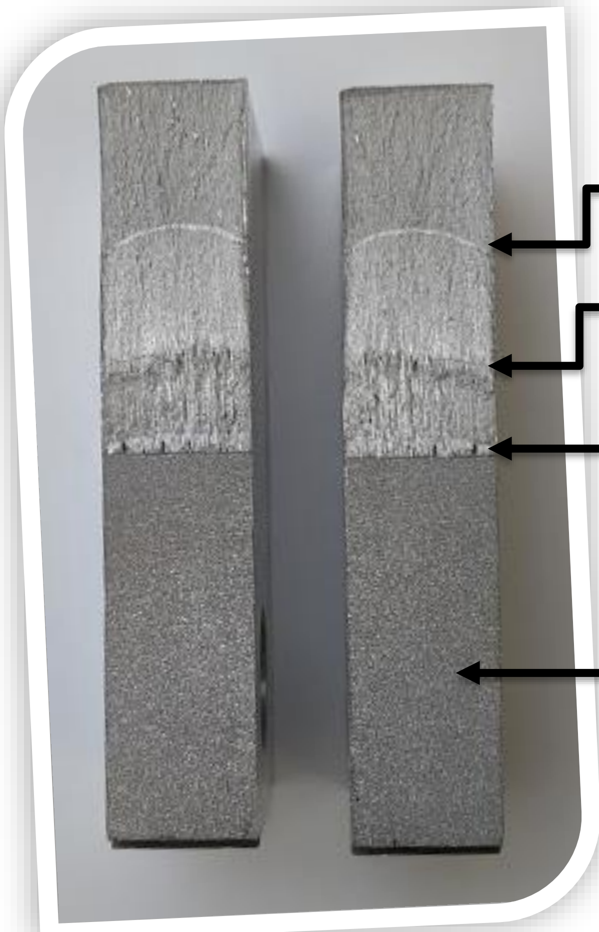
Auditing FCGR Testing



End of Segment 2

End of Segment1

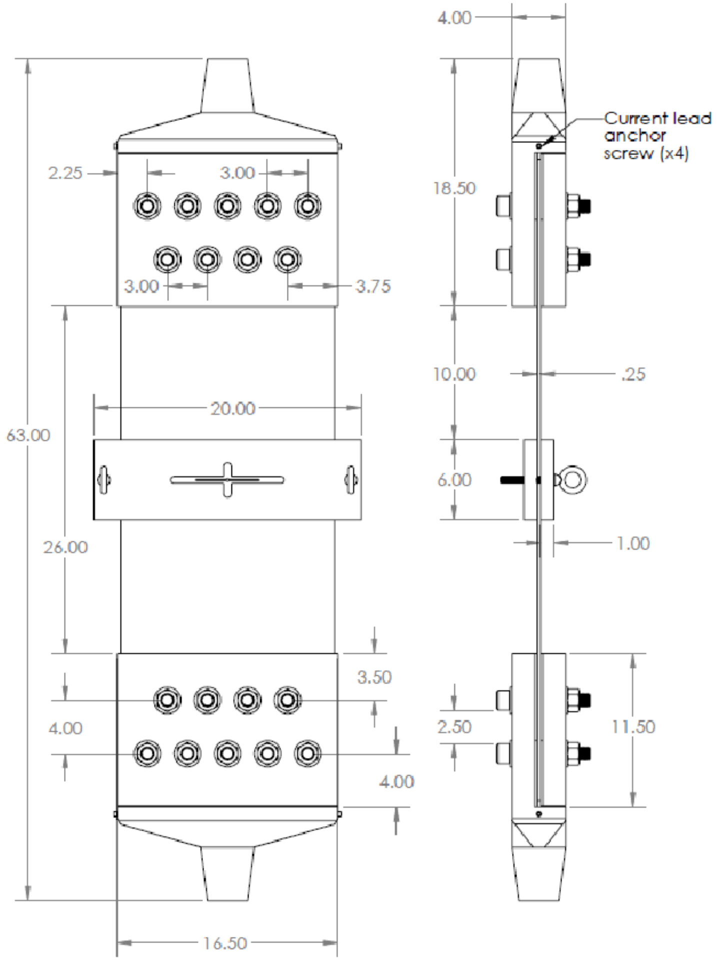
Precrack

Notch

- Cracks are measured after test completion to post-test correct analysis.
- Corrects the error between the measured crack and actual crack lengths and crack curvature.

AC7101/3 Rev D § 12.21

Auditing FCGR Testing



- Anti-buckling guides are often used when testing thin M(T) specimens.
- These thin specimens are often loaded in tension-compression, which can cause buckling.
- These plates add stiffness to the structure and prevent buckling.

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Summary

- Fatigue tests covered by AC7101/3 include: LCF, HCF, and FCGR.
- Common specimens were covered for each test type.
- Basic setup discussed for each test type.
- Testing issues identified for each test type.

QUESTIONS?

THANK YOU.

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