



# **How Inspectors Can Use Fracture Mechanics**

**by Roger Cordes, Ph.D., P.E.**

## Roger Cordes, Ph.D., P.E.



an employee-owned company

- Involved with a wide variety of solid mechanics projects for SES' Floating Production Systems and Fitness-For-Service groups.
- Generally focused on solid mechanics analyses including strength and fatigue assessments.
- Involved in contact problems, damage evolution, dynamic/impact simulations, post-buckling behavior, thermal behavior, and crack modeling.
- Crack assessment projects at SES include prediction of crack growth rates and component life, maximum acceptable initial flaw size studies, and forensic work.
- B.S.M.E from the University of Arkansas and a Ph.D. from Northwestern University. Licensed Professional Engineer in Texas.



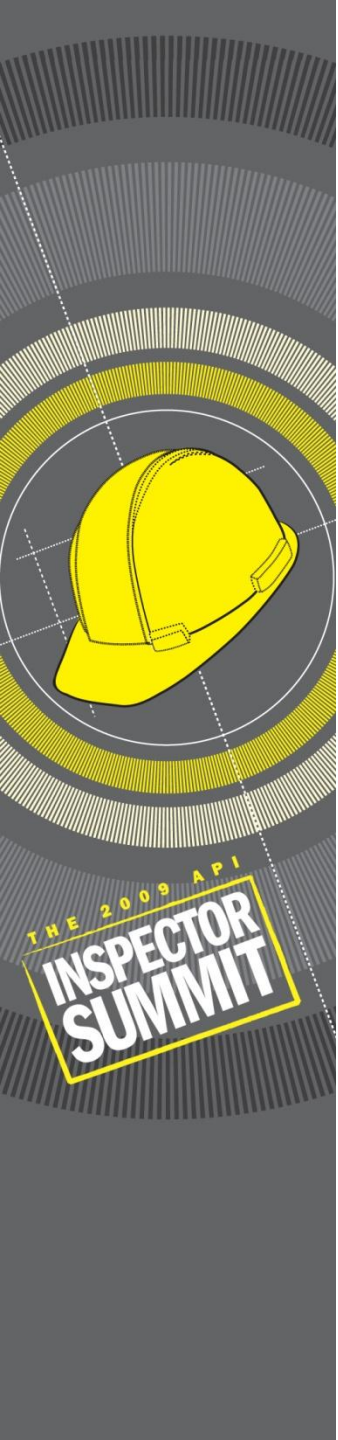
# Purpose of Presentation: Discussing how fracture models can be used in conjunction with inspections

## ■ Overview

- Typical analyses
- Basic fracture mechanics
- Material toughness and critical crack sizes
- Fatigue crack growth and ECAs
- Inputs needed and safety factors

## ■ Sources

- API 579 "Fitness for Service"
- British Standard 7910 "Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures"
- API 1104 "Welding of Pipelines and Related Facilities"



# Overview

Relating fracture mechanics to inspections

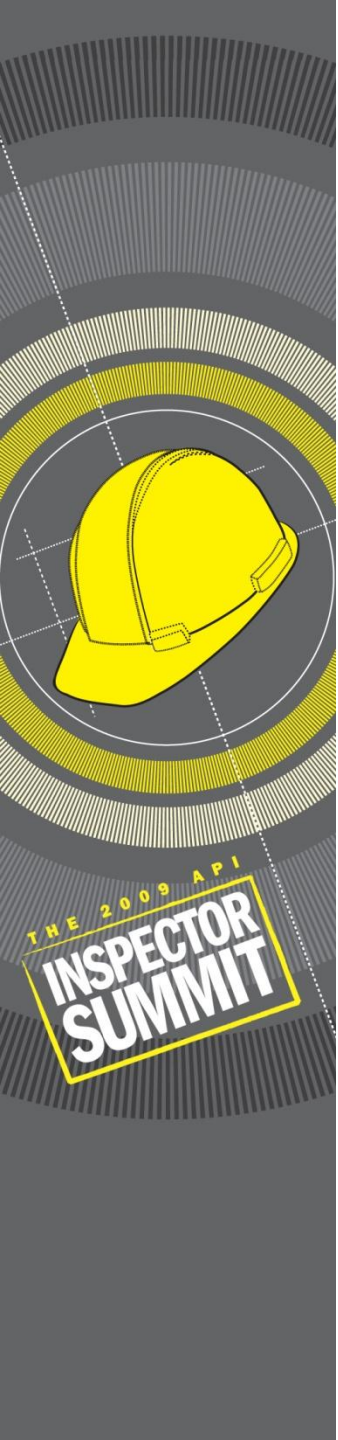
Typical analyses

Basic fracture mechanics

Material toughness and critical crack sizes

Fatigue crack growth and ECAs

Inputs needed and safety factors



# Typical Analysis

**A Stress Analysis of a Pipe,  
Vessel, Component**

Stresses

Can it survive the  
loading?

(Strength Check)

How long is it predicted  
to last?

(Fatigue Check)



# How Fracture Mechanics Fits In

**A Stress Analysis of a Pipe,  
Vessel, Component**

Stresses

How big a crack can  
survive the loading?

(Flaw tolerance/  
Toughness Check)

How fast will a crack  
grow?

How big an initial  
crack is OK?

(Inspection Interval Check)

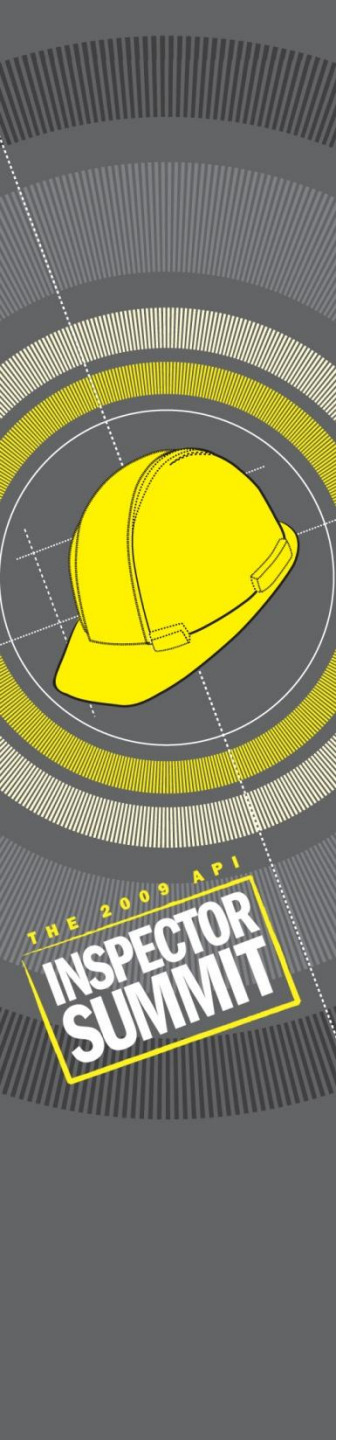
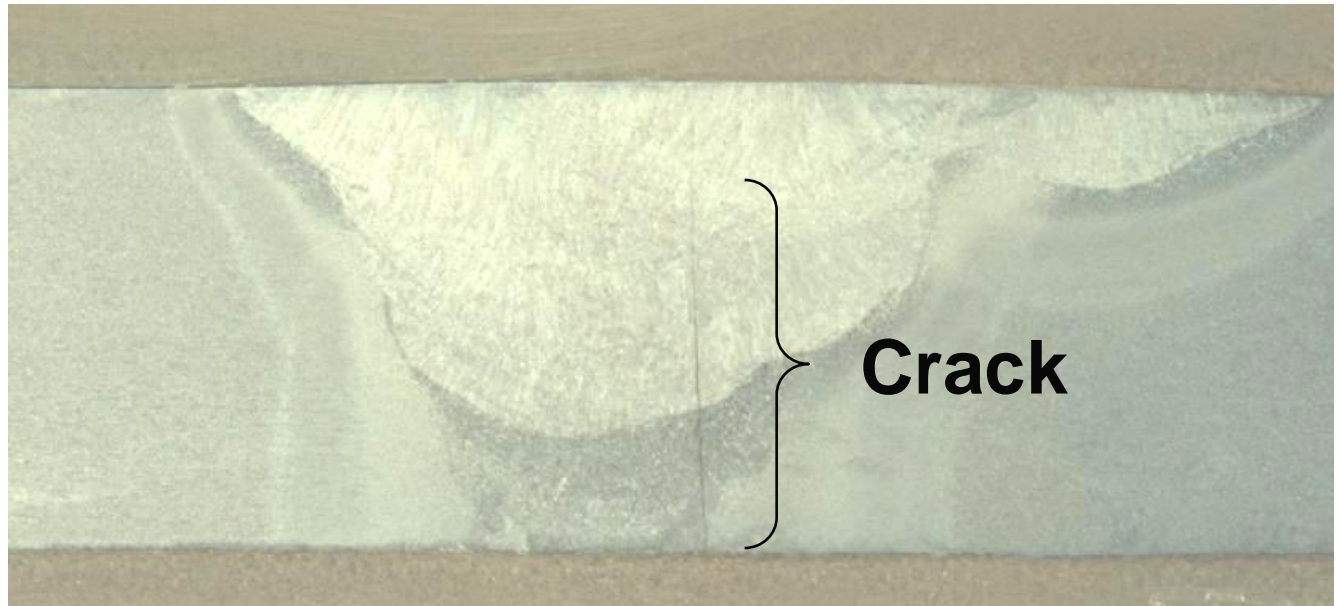


# Nomenclature

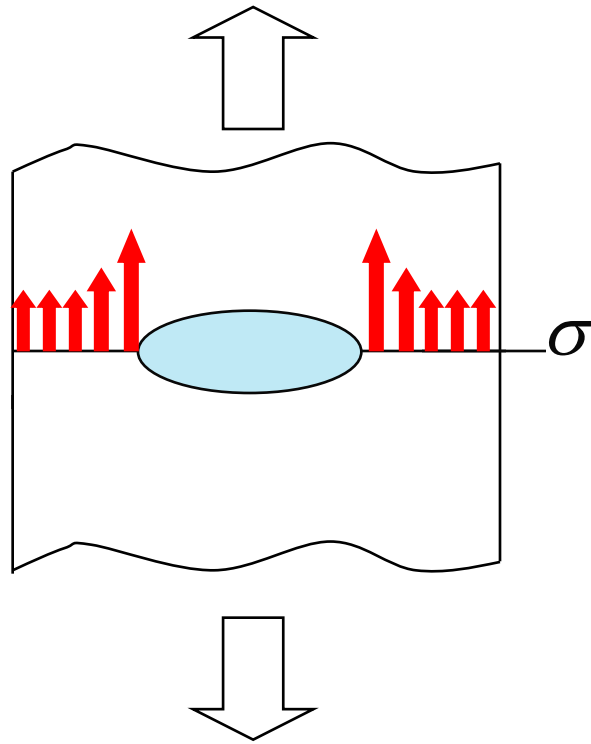
Inspectors find “indications”.

If the indication is larger than a pre-defined acceptable size, it is a “defect”.

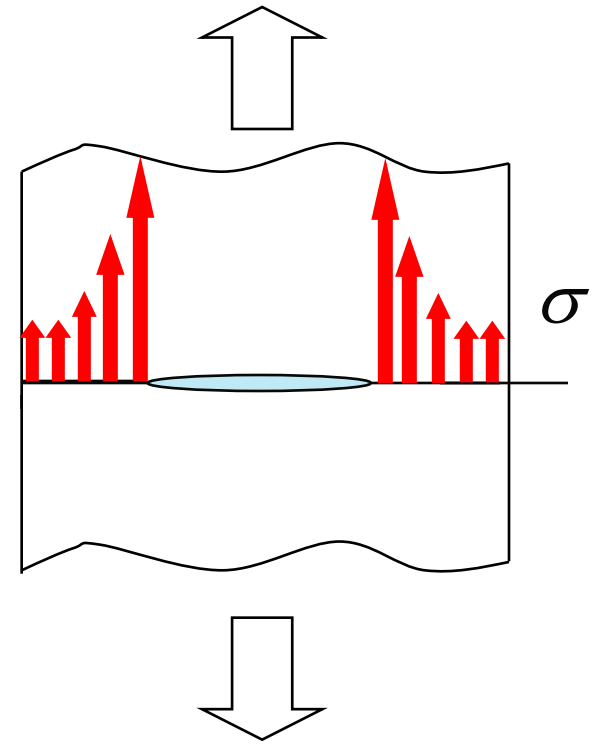
If the indication is sharp, it is a “crack”.



# The Basics of Fracture Mechanics (1)



If you pull on something with a void or particle in it, you get a stress concentration factor (SCF).



If you flatten that void, you get a crack with a stress intensity factor (K).

## The Basics of Fracture Mechanics (2)

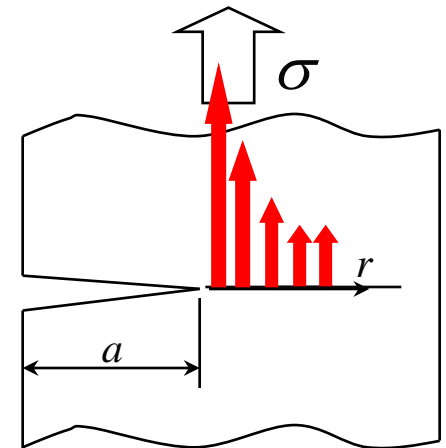
- The stress field at the tip of the crack can be written in the following form:  $K = Y\sigma\sqrt{a}$

$\sigma$  is the far field stress,

$Y$  is a function of the geometry,

$a$  is the crack length, and

$K$  is the stress intensity factor.



### 2 Options

$$K < K_{MATERIAL}$$

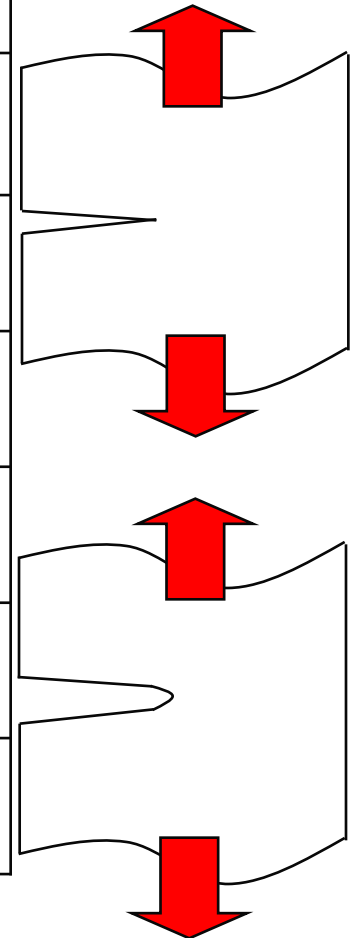
Failure not predicted ↓

$$K \geq K_{MATERIAL}$$

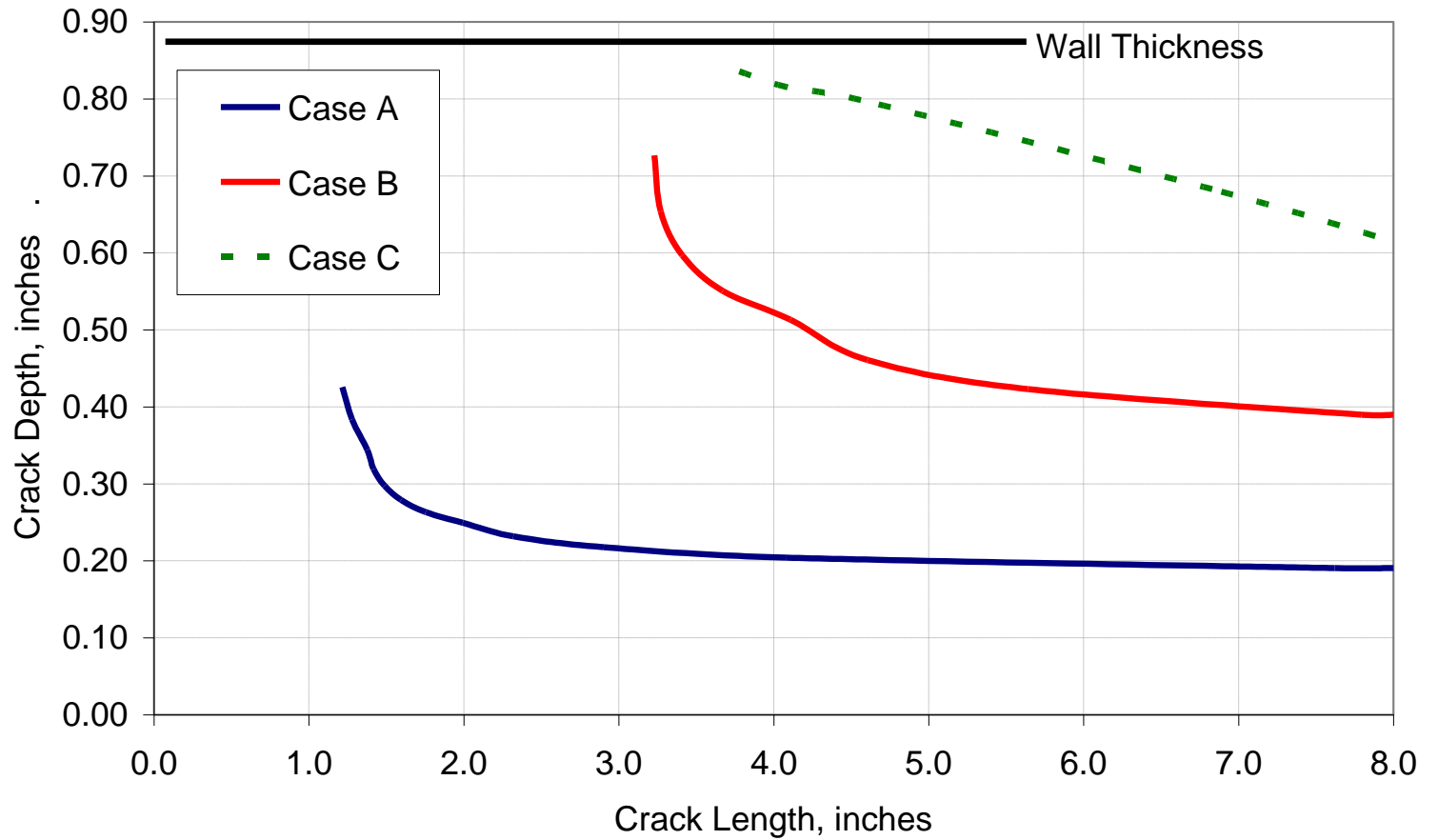
Failure predicted

# Fracture Toughnesses

| Material  | Approximate Values |             |   |
|-----------|--------------------|-------------|---|
|           | Charpy (ft-lbs)    | CTOD (mm)   | $K_{\text{MATERIAL}}$ (ksi* $\sqrt{\text{in.}}$ ) |
| Glass     | <1                 | <0.01       | 1-5   |
| Aluminum  | 5-25               | 0.1 to 0.6  | 20-50   |
| Titanium  | 10-50              | 0.1 to 0.7  | 60-100  |
| Cast Iron | 10-30              | 0.1 to 0.5  | 30-90   |
| Steel     | 40-250             | 0.05 to 2.0 | 100-250   |

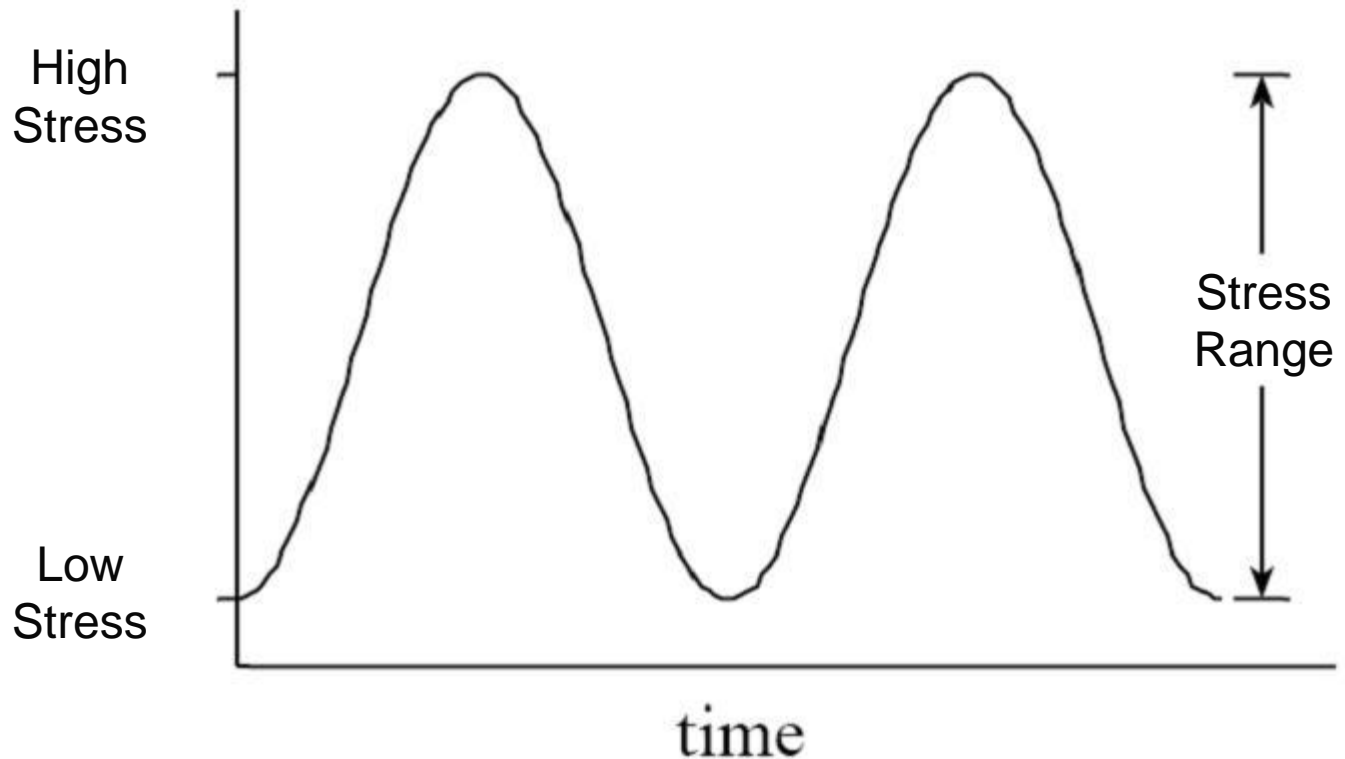


# Surface Crack Example



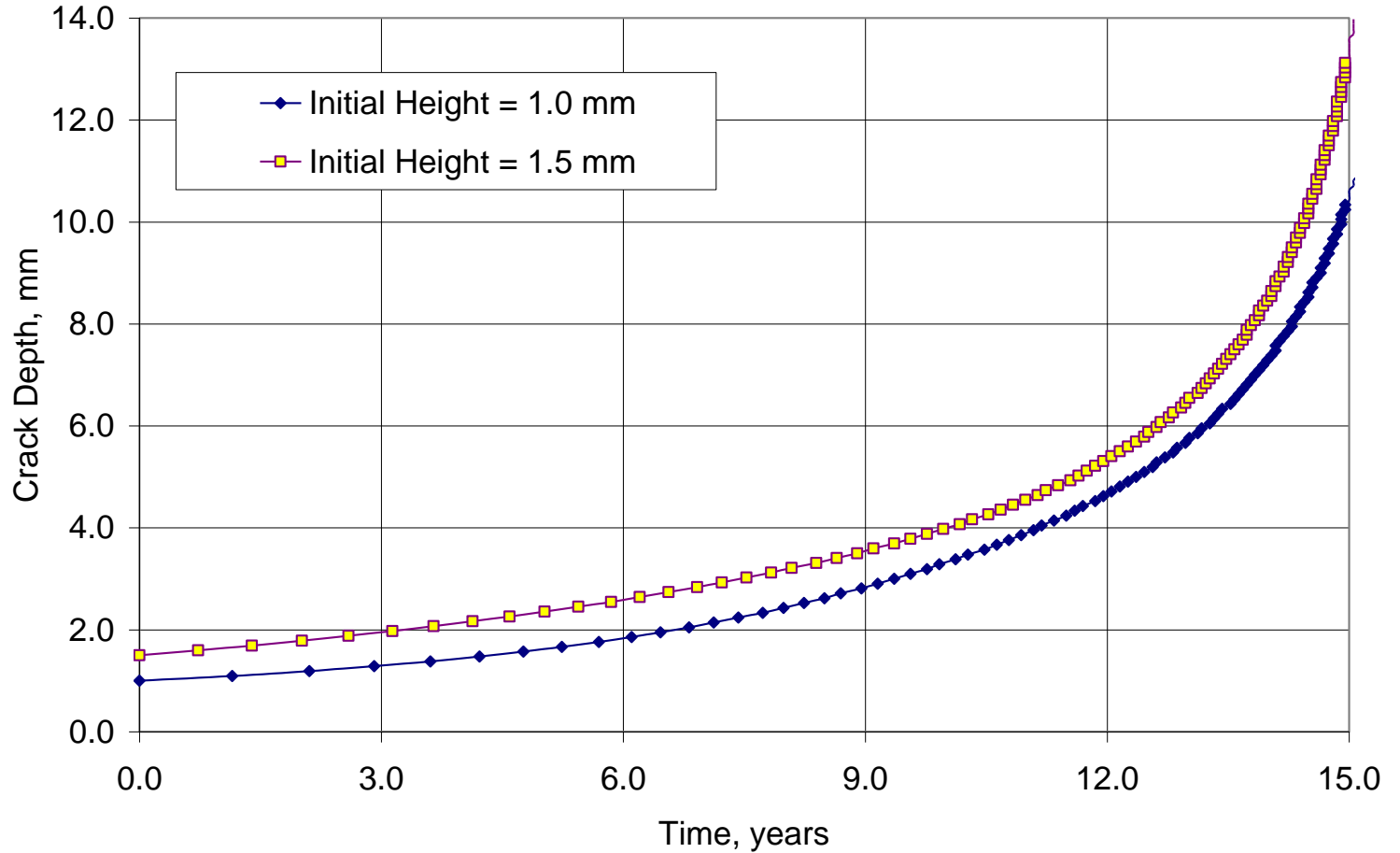
# Fatigue Crack Growth

Cracks mainly grow from the stress range during cyclic loading.



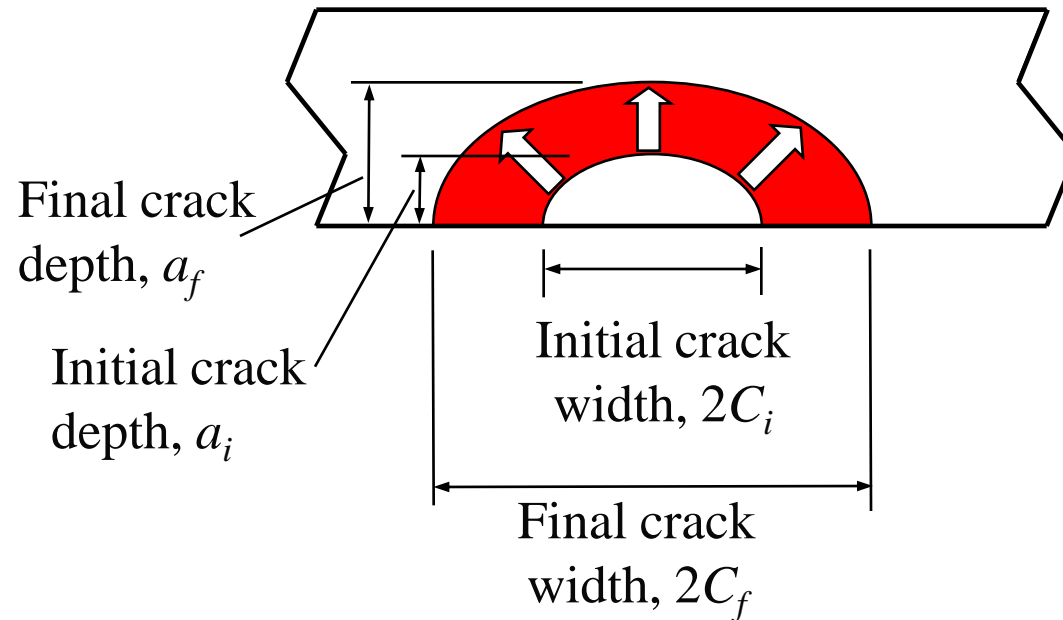
# Crack Growth

OD Surface Crack Depth Growth versus Time



THE 2009 API  
**INSPECTOR  
SUMMIT**

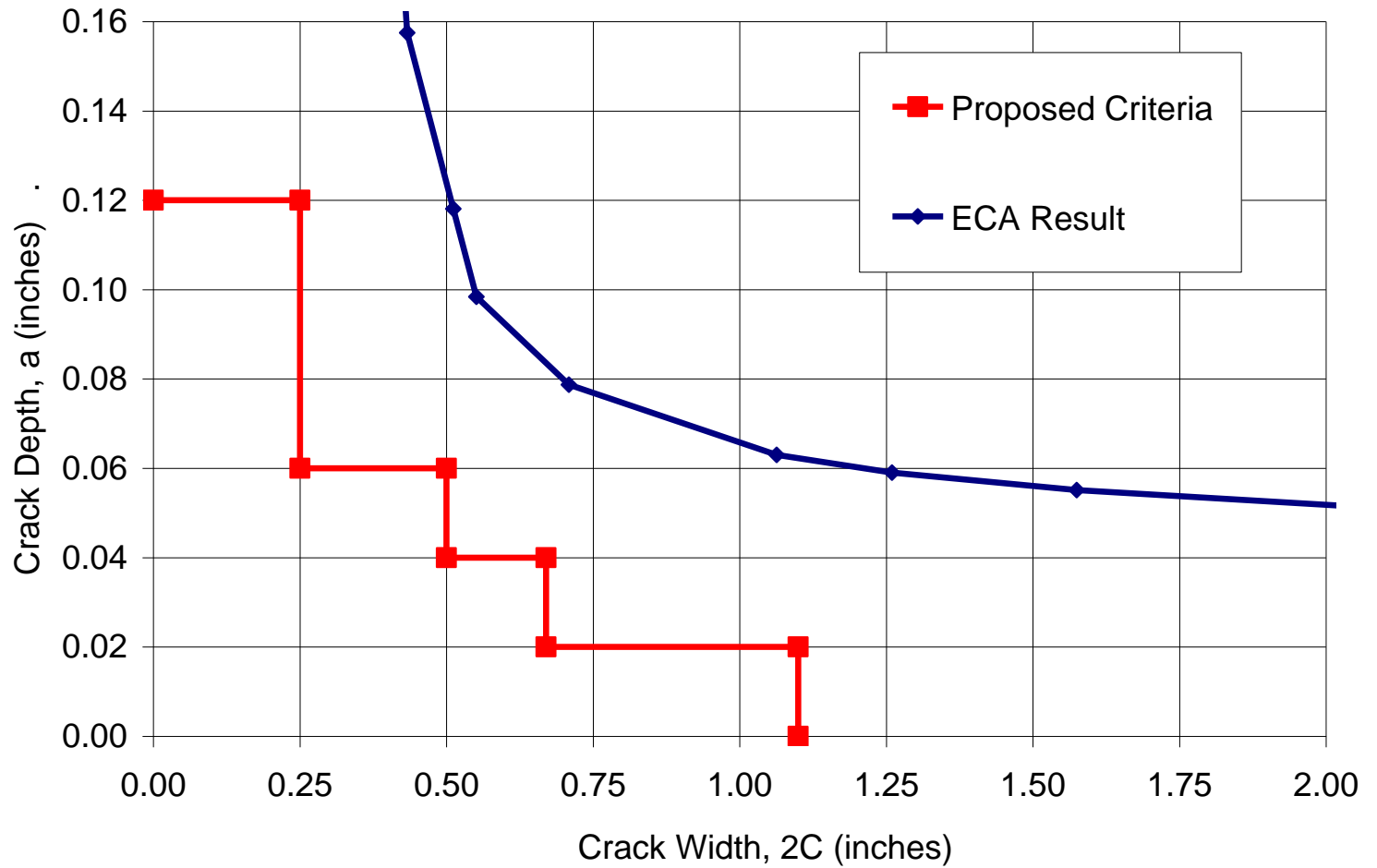
# Crack Growth Over Time



## ECA=Engineering Critical Assessment

Commonly used to determine the *initial* crack sizes that are OK based on the expected loading over the life of the component.

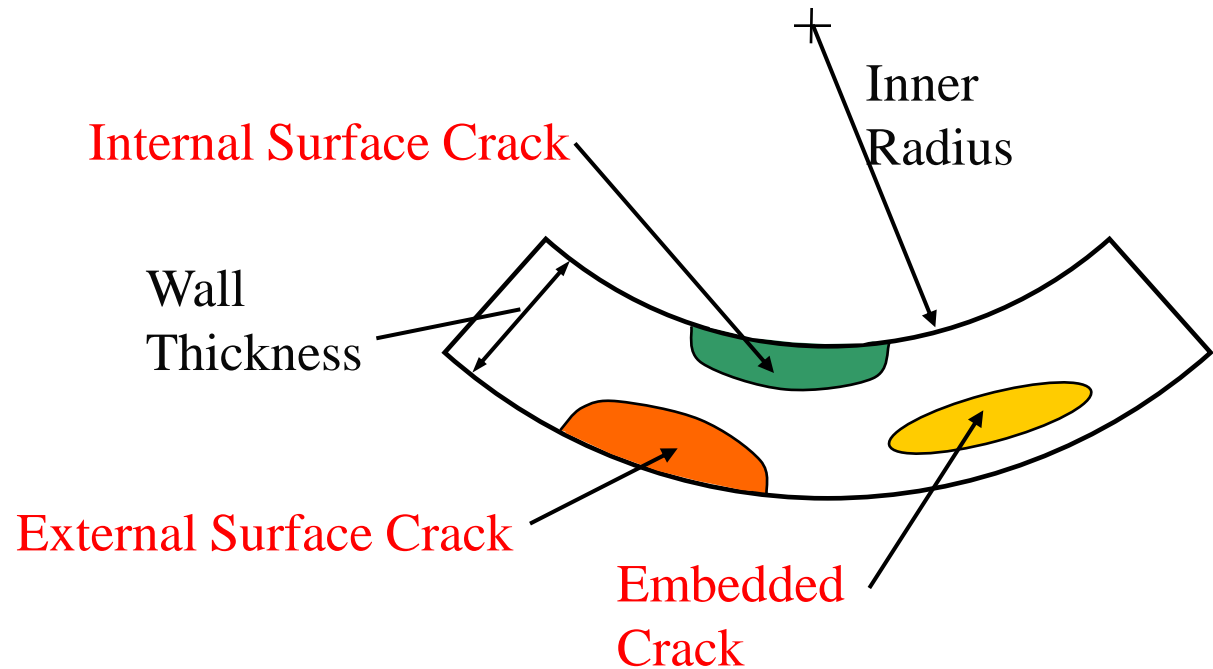
# ECA Results



# Crack Locations and Orientations

Acceptable crack criteria can be define for

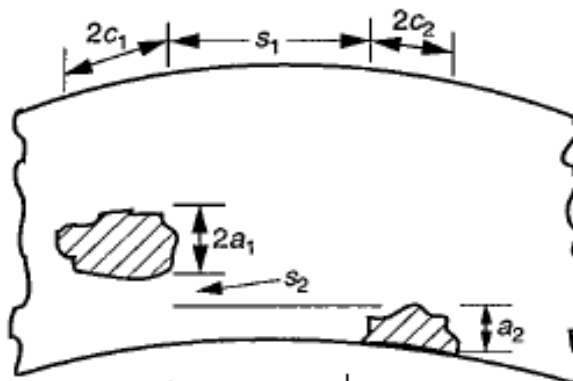
- Circumferential cracks driven by axial stress
- Axial cracks driven by hoop stress



# Interaction Rules

If cracks are too close together, they are treated as one crack.

Case 3



$$s_1 < c_1 + c_2$$

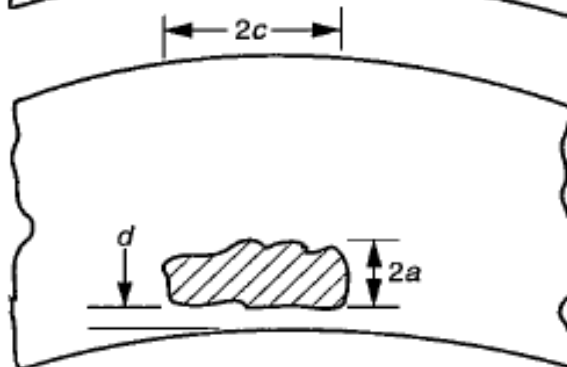
and

$$s_2 < a_1 + a_2/2$$

$$a_e = 2a_1 + s_2 + a_2$$

$$2c_e = 2c_1 + s_1 + 2c_2$$

Case 4



$$d < a$$

$$a_e = d + 2a$$

$$2c_e = 2c$$



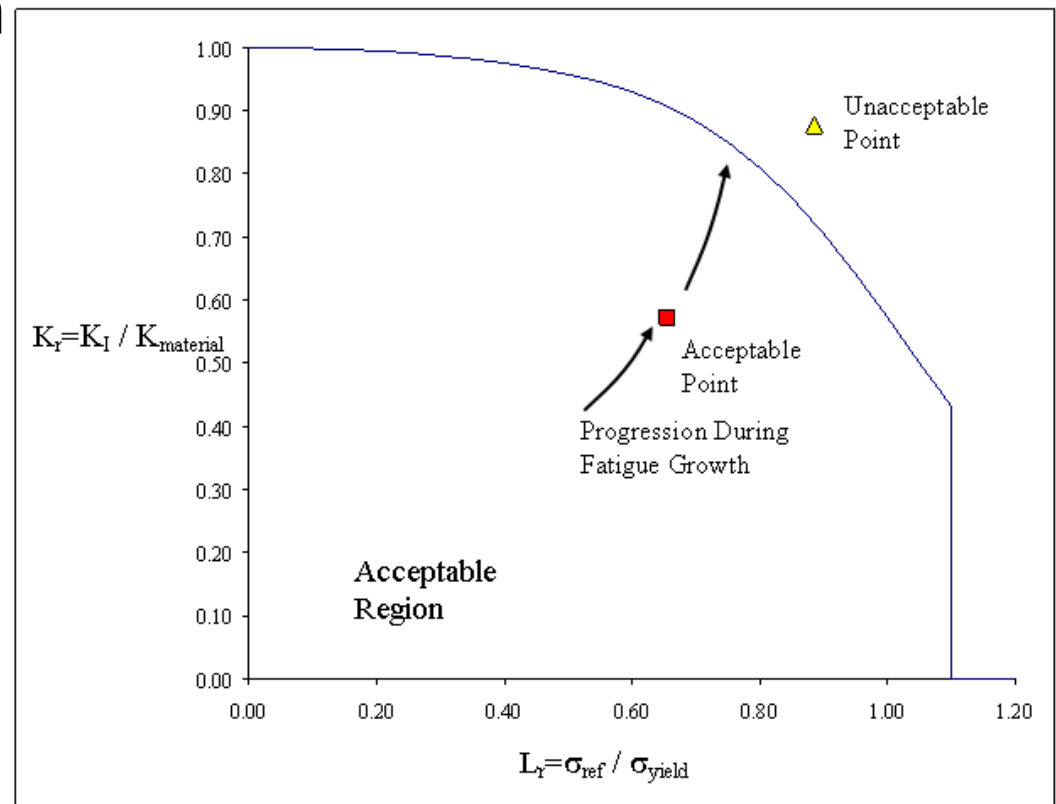
# API 579 "Fitness for Service" and British Standard 7910

Failure assessment diagram (FAD) approach is used for the ECA (API 579) and BS7910.

FAD based on

- K
- Plastic Collapse

**FAD**



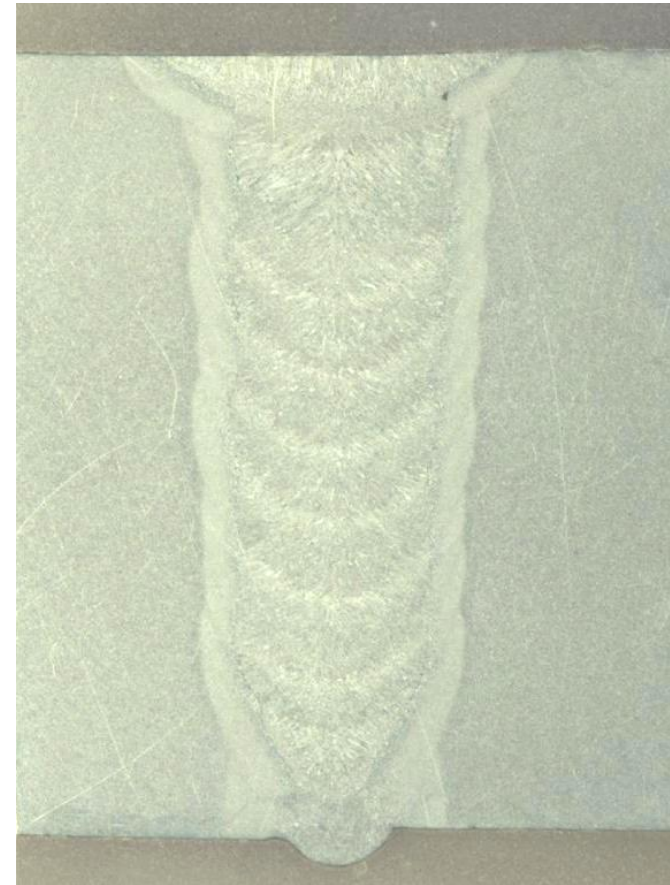
# Inputs for Analysis

## ■ Significant inputs driving the solution:

- Geometry
- SCF
- Primary Cyclic Loading
- Crack Growth Constants
- Target Life
- Initial Crack Size
- Material Toughness

## ■ Other inputs

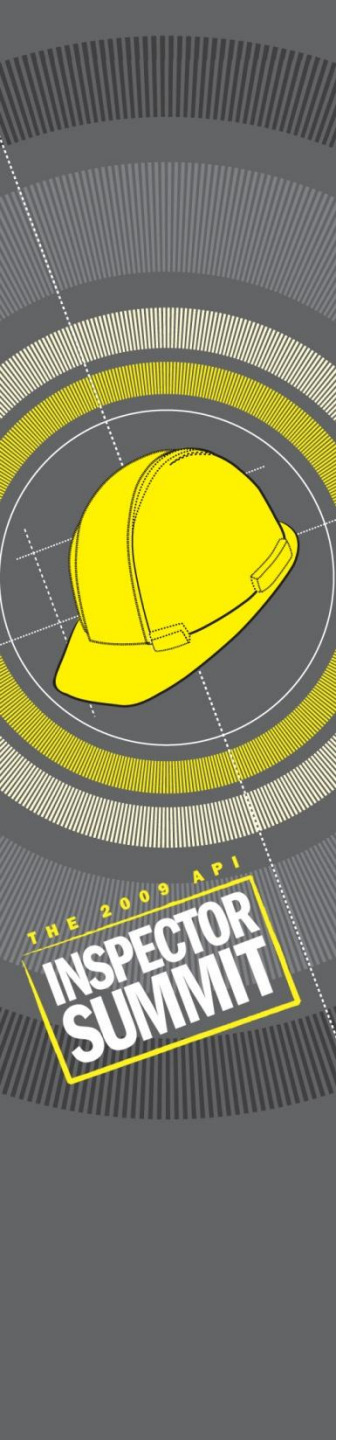
- Residual Stress
- Maximum Primary Stress
- Yield/Ultimate Strengths



# Safety Factors

API 579 utilizes safety factors on three items:

- Applied Loading
- Fracture Toughness
- Crack Size



# How Fracture Mechanics Fits In

## Before Putting a Component in Operation

Do Fracture Mechanics Evaluation



Determine Allowable Flaw Sizes for Life of Vessel



Set Inspection Criteria

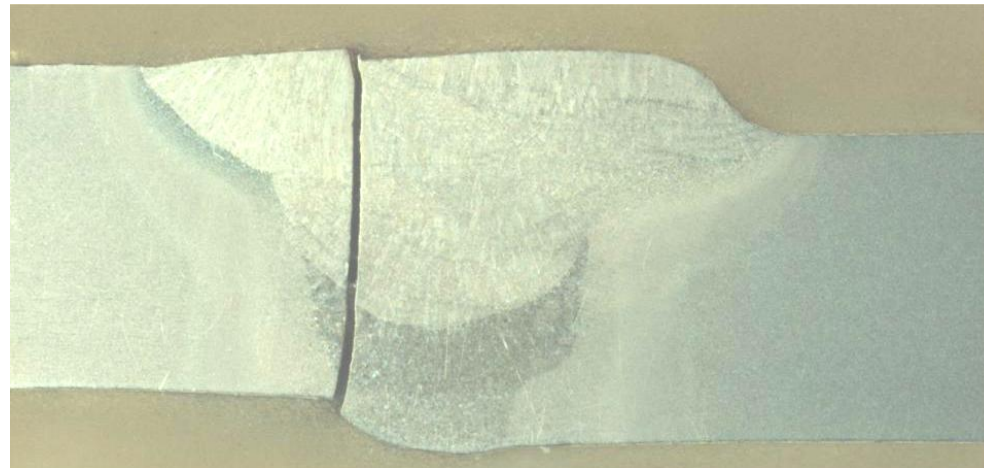
## If You Inspect and Find a Crack During Operation

Do Fracture Mechanics Evaluation



See How Big Crack Can Get  
Or

See How Fast Crack Will Grow



# Questions ???

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