AE 737 - MECHANICS OF DAMAGE TOLERANCE

Lecture 9

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OFFICE HOURS

- No Office Hours Friday :(
- Raincheck office hours Monday 3:00 - 5:00
- Homework 4 due Thursday, 25 Feb.

SCHEDULE

- 18 Feb - Residual Strength
- 23 Feb - Residual Strength, Multiple Site Damage
- 25 Feb - Multiple Site Damage, Mixed-mode Fracture, Homework 4 Due, Homework 5 Assigned
- 1 Mar - Section 1 Review, Homework 5 Due
- 3 Mar - Section 1 Review, Homework 5 return
- 8 Mar - Exam 1
- 10 Mar - Exam return, Final Project discussion

OUTLINE

1. thickness effects
2. fracture toughness review
3. residual strength
4. fedderson approach
5. proof testing

THICKNESS EFFECTS

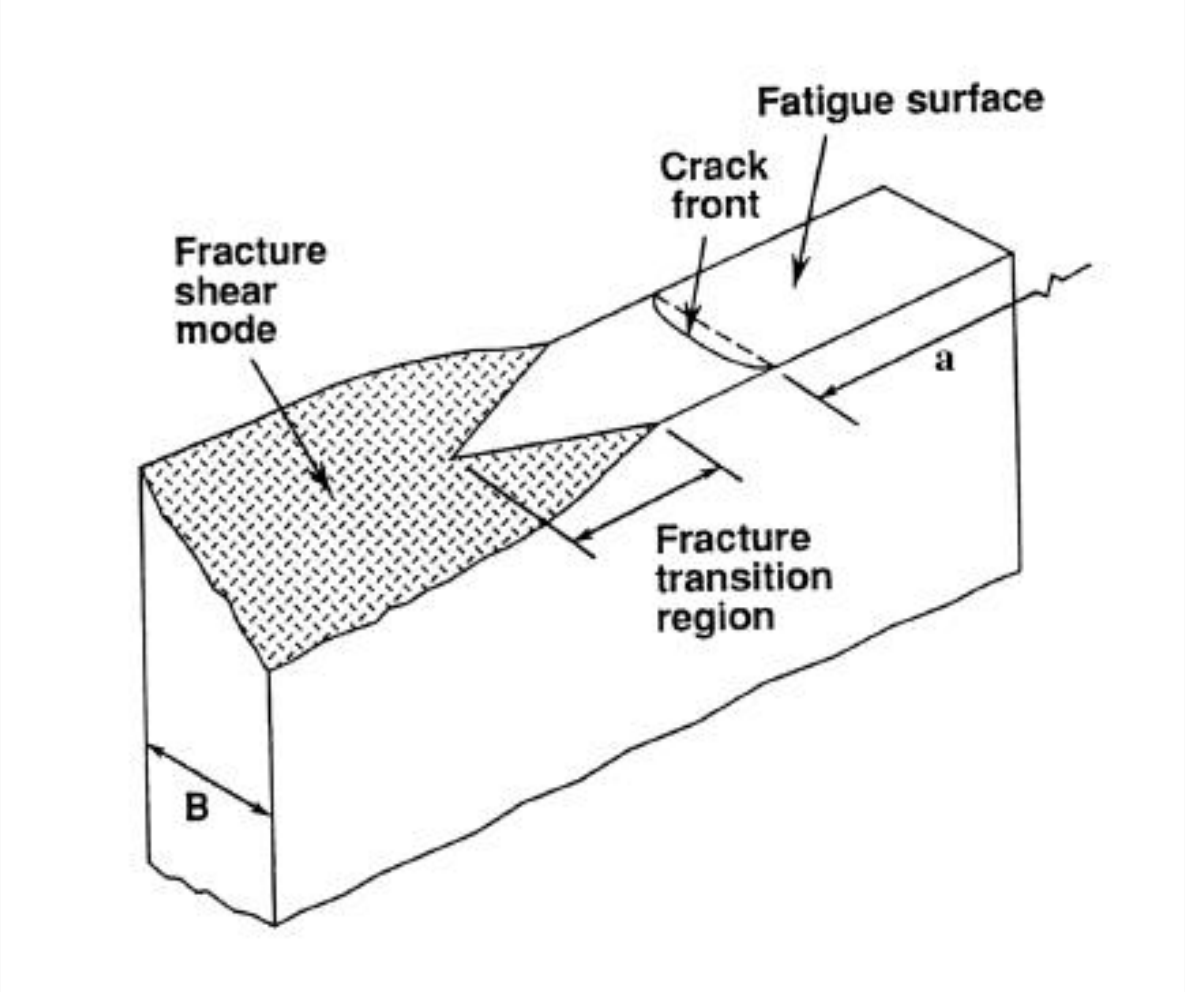
THICKNESS EFFECTS

- We already know there is a difference between plane strain and plane stress fracture toughness
- As a material gets thicker and thicker, it converges to the plane strain solution
- Thinner specimens tend towards the plane stress solution
- When a specimen is thinner than some critical thickness, the material behavior is somewhat unknown
- Some materials retain the constant plane stress fracture toughness
- Others exhibit an unpredictable decrease in fracture toughness
- The phenomenon is not well-understood

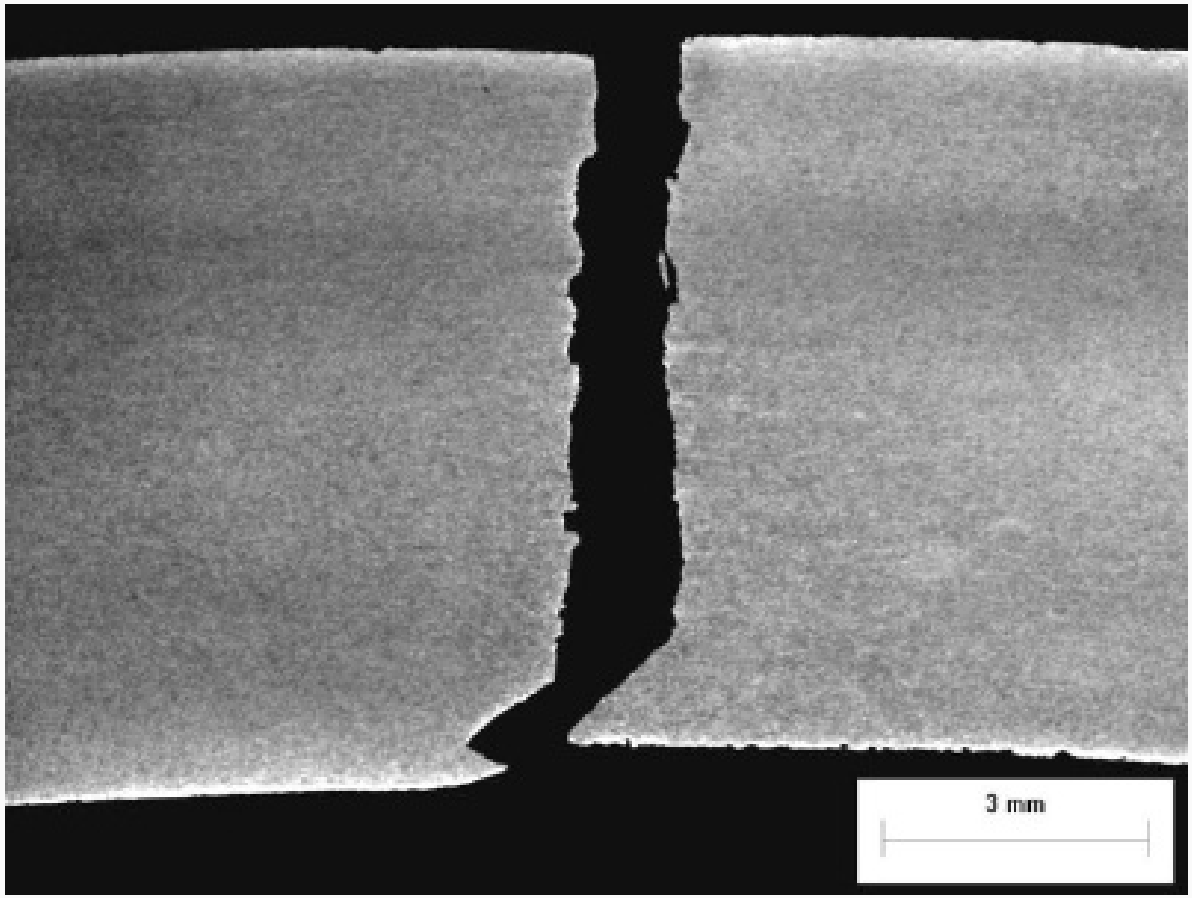
THICKNESS EFFECTS

- There is also a difference in the fracture surface between thin and thick specimens
- Thin specimens (in plane stress region) fail due to slant fracture
- This actually indicates some mixed-mode conditions at failure
- Thick specimens fail due to square fracture (with a small shear tip near the edges)
- This is more consistent with pure Mode I

SLANT FRACTURE



SHEAR LIP



FRACTURE TOUGHNESS REVIEW

GROUP REVIEW

- Group 1 - Sketch K_R-curve (for ductile material), explain what it means, how to find K_c
- Group 2 - Sketch K_c vs. crack length, explain what's happening
- Group 3 - How can we determine whether a panel is in plane strain or plane stress?
- Group 4 - Sketch K_R-curves for ductile and brittle materials, what is the difference?

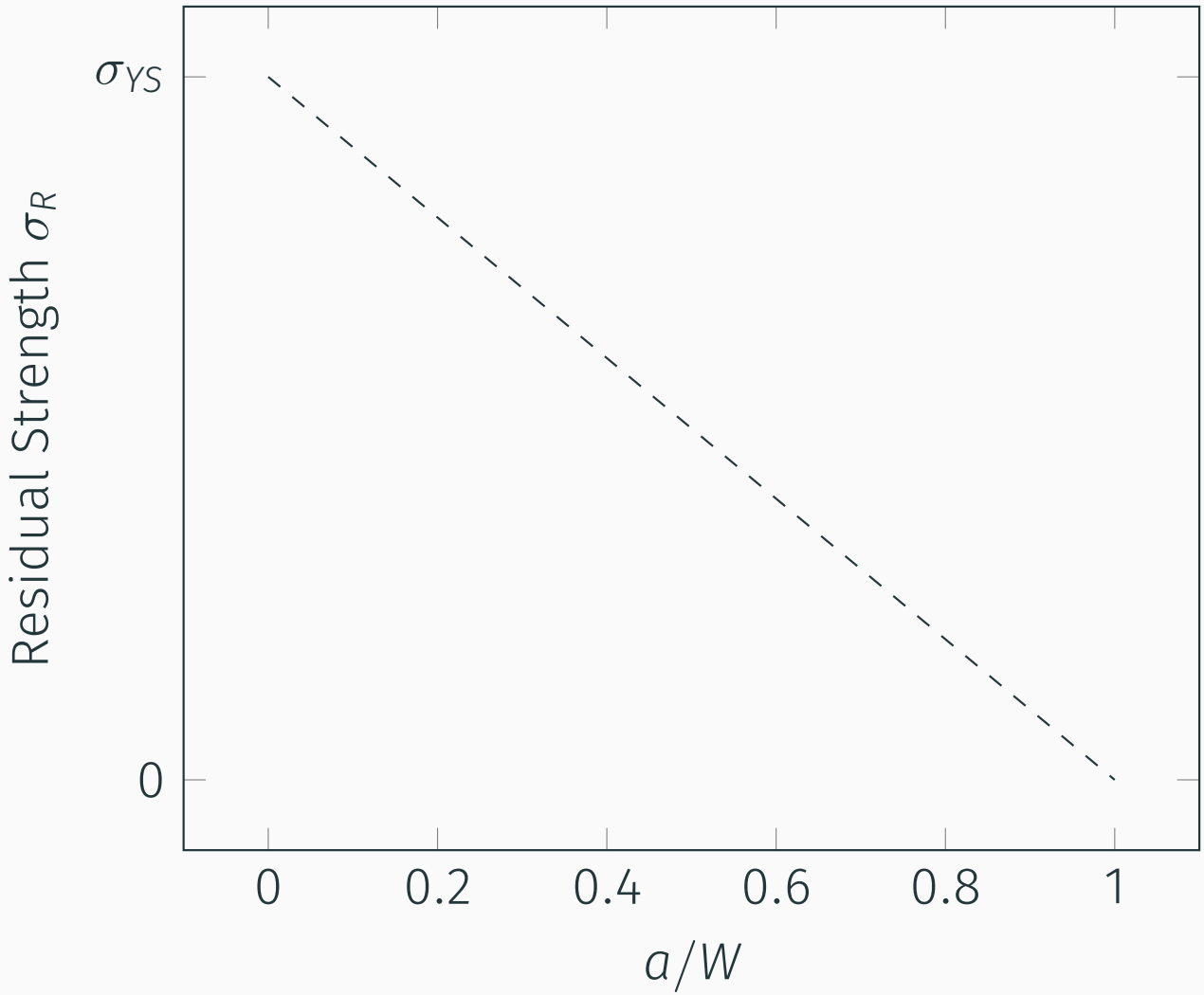
RESIDUAL STRENGTH

RESIDUAL STRENGTH

- In the last chapter we performed some basic residual strength analysis by checking for net section yield
- As the crack grows, the area of the sample decreases, increasing the net section stress
- The residual strength, σ_R is given in terms of the gross area, so as the crack grows the residual strength due to yield decreases
- We can relate the net-section stress to σ_R by

$$\sigma_R = \sigma_{YS} \frac{A_{net}}{A_{gross}} \tag{9.1}$$

RESIDUAL STRENGTH

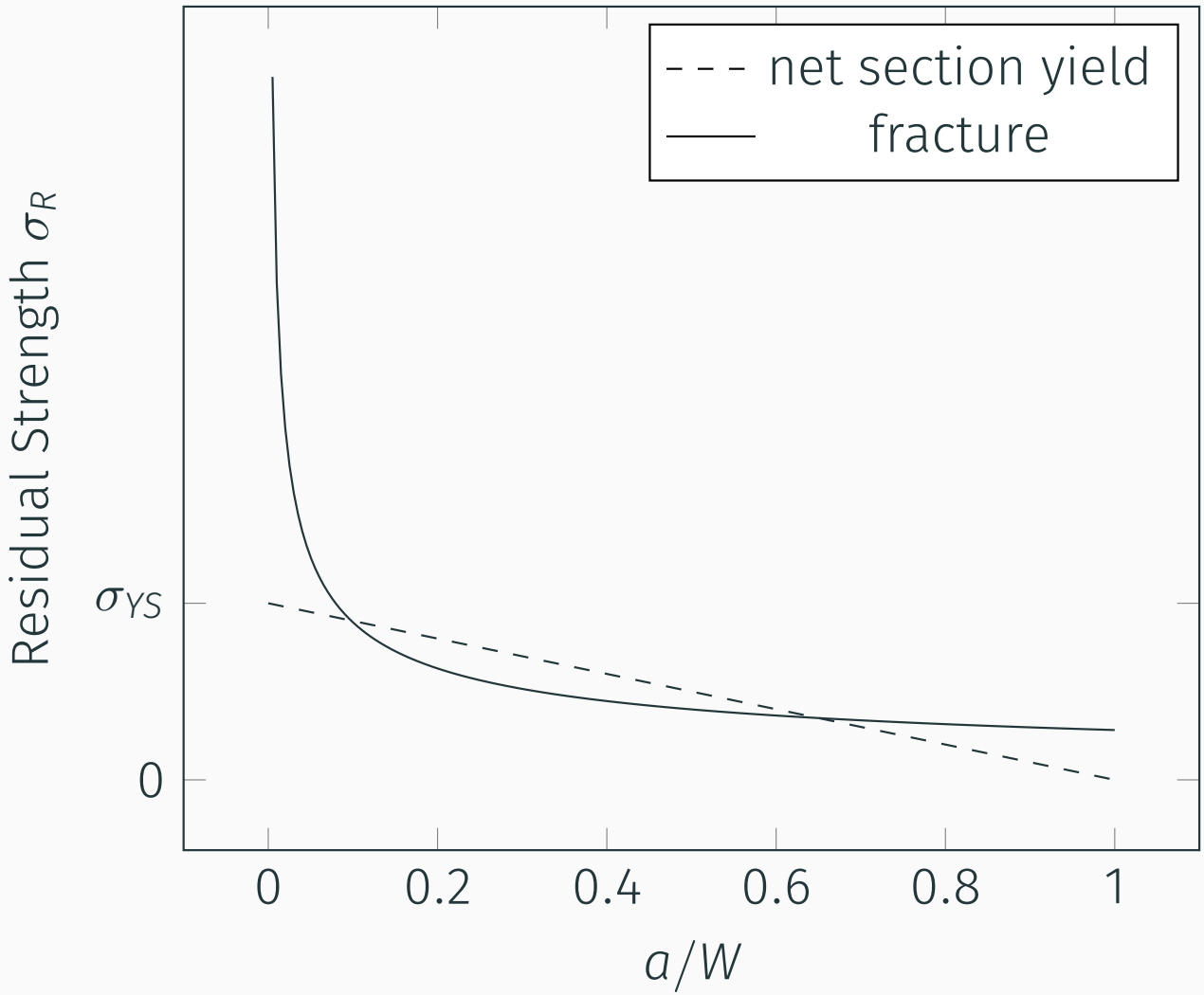


RESIDUAL STRENGTH

- For brittle fracture to occur, we need to satisfy the condition
-

$$\sigma_R = \sigma_C = \frac{K_C}{\sqrt{\pi a}\beta} \tag{9.2}$$

RESIDUAL STRENGTH



RESIDUAL STRENGTH

- Within the same family of materials (i.e. Aluminum), there is generally a trade-off between yield stress and fracture toughness
- As we increase the yield strength, we decrease the fracture toughness (and vice versa)
- Consider a comparison of the following aluminum alloys
  1. 7178-T6, $K_C = 43$ ksi$\sqrt{\text{in.}}$, $\sigma_{YS} = 74$ksi
  2. 7075-T6, $K_C = 68$ ksi$\sqrt{\text{in.}}$, $\sigma_{YS} = 63$ksi
  3. 2024-T3, $K_C = 144$ ksi$\sqrt{\text{in.}}$, $\sigma_{YS} = 42$ksi

RESIDUAL STRENGTH

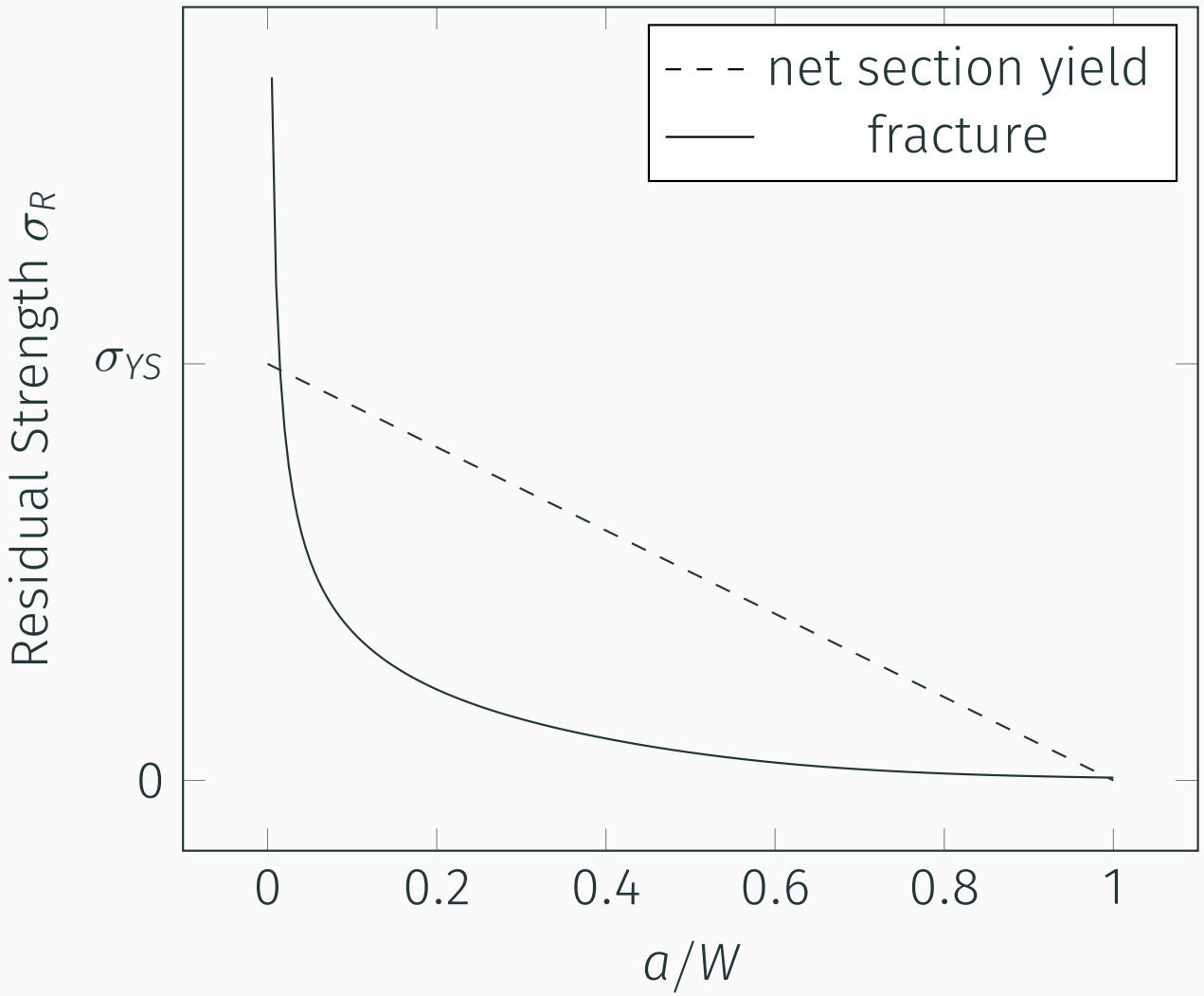
- As an example let us consider an edge-cracked panel with $W = 6''$ and $t = 0.1''$
- The net section yield condition will be given by
- $$\sigma_C = \sigma_{YS} \frac{W - a}{W} = \sigma_{YS} \frac{6 - a}{6}$$
- And the fracture condition by

$$\sigma_C = \frac{K_C}{\sqrt{\pi a}\beta}$$

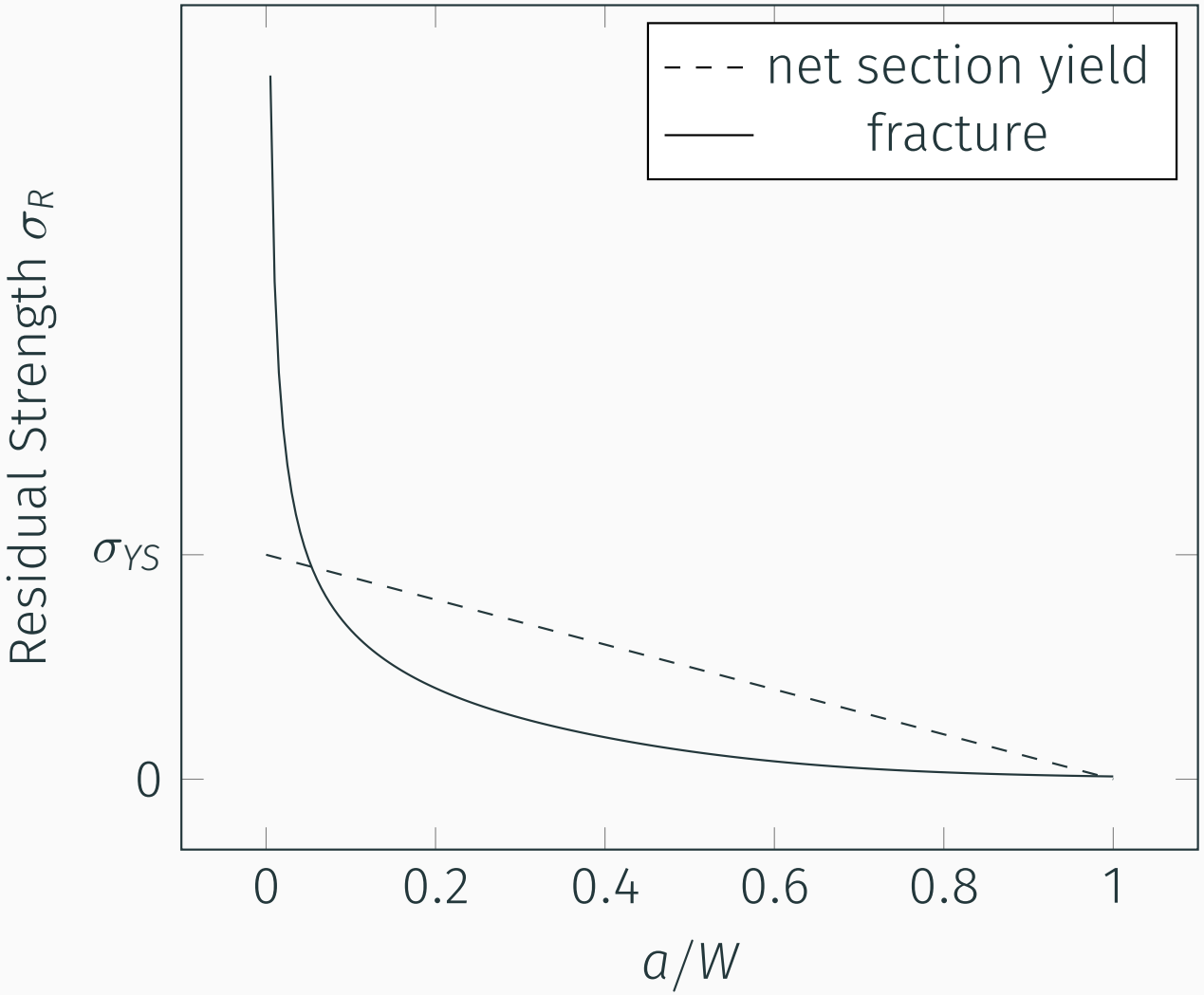
With

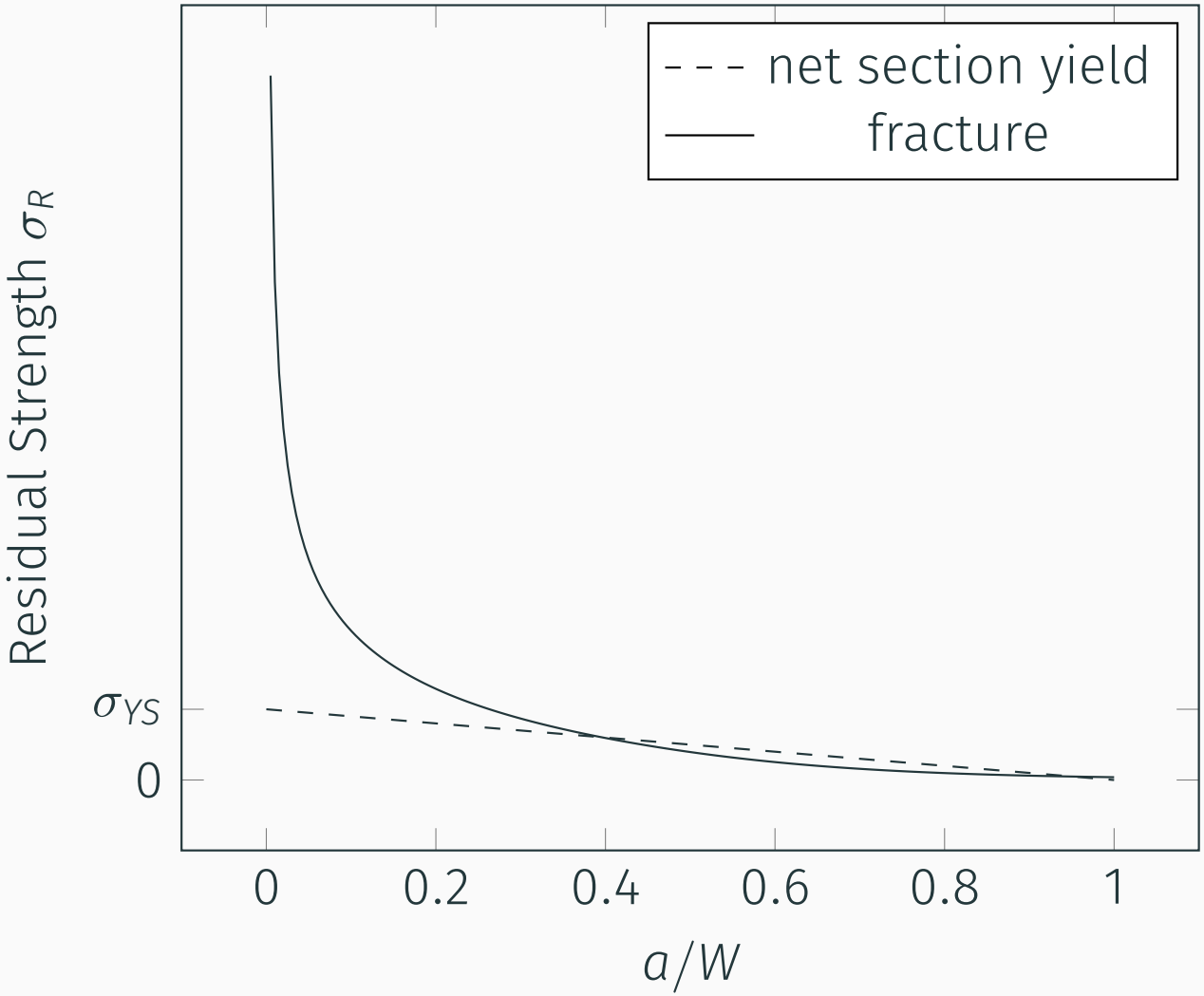
$$\beta = 1.12 - 0.231 \left(\frac{a}{W}\right) + 10.55 \left(\frac{a}{W}\right)^2 - 21.72 \left(\frac{a}{W}\right)^3 + 30.39 \left(\frac{a}{W}\right)^4$$

7178-T6

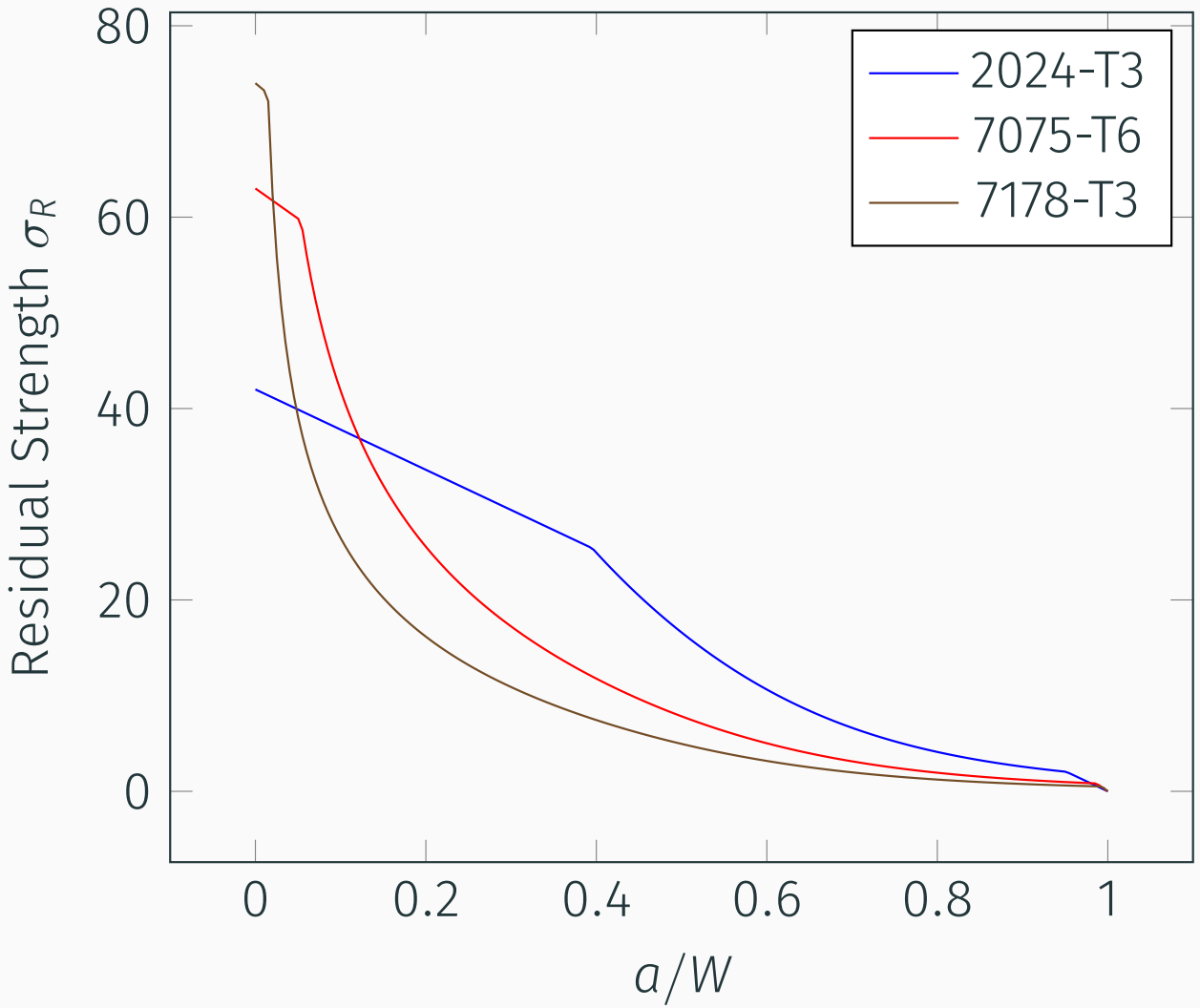

net section yield
fracture
Residual Strength σ_R
σ_{YS}
0
0
0.2
0.4
0.6
0.8
1
a/W

7075-T6


net section yield
fracture
Residual Strength σ_R
σ_{YS}
0
0
0.2
0.4
0.6
0.8
1
a/W


net section yield
fracture
Residual Strength σ_R
σ_{YS}
0
0
0.2
0.4
0.6
0.8
1
a/W

COMPARISON


80
60
40
20
0
Residual Strength σ_R
0
0.2
0.4
0.6
0.8
1
a/W
2024-T3
7075-T6
7178-T3

USING MIL-HANDBOOK

- Uses a different grain nomenclature

K_C	σ_{YS}
L-T	L
T-L	L-T

- A-Basis vs. B-Basis values are reported (A = 99% of population will meet/exceed value, B = 90% of population)
- S-Basis - no statistical information available, standard value to be used

USING MIL-HANDBOOK

- F_{tu} - ultimate tensile strength
- F_{ty} - tensile yield strength
- F_{cy} - compressive yield strength
- F_{su} - ultimate shear strength
- F_{bru} - ultimate bearing strength
- F_{bry} - bearing yield strength
- E - tensile Young's Modulus
- E_c - compressive Young's Modulus
- G - shear modulus
- μ - Poisson's ratio

FEDDERSON APPROACH

FEDDERSON APPROACH

- Unfortunately, the method we described above does not quite match experimental results
- Fedderson proposed an alternative, where we connect the net-section yield and brittle fracture curves with a tangent line
- This approach agrees very well with experimental data
- Note: We could do something similar when the crack is very long, but we are generally less concerned with this region (failure will have already occurred)

PROOF TESTING

PROOF TESTING

- Proof testing is a way to use the concept of residual strength to check the size of a defect from manufacturing
- Due to the fatigue life of a certain panel, and/or an inspection cycle that we have prescribed for that part, we determine an ”acceptable” initial flaw size, a_0
- We then determine a load which would cause failure at this crack length
- This is the ”proof load”
- If the part does not fail in the proof test, we can assume that the largest flaw in the material is a_0

EXAMPLE

- Suppose we are concerned about edge cracks in a panel with $\sigma_{YS} = 65\text{ksi}$, $W = 5$”
- We have determined that the largest allowable crack is 0.4”
- The fracture toughness of this panel is $K_c = 140\ \text{ksi}\sqrt{\text{in.}}$
- We can find the proof load

$$\begin{aligned}\sigma_c &= \frac{K_c}{\sqrt{\pi a_0}\beta} \\ &= \frac{140}{\sqrt{\pi 0.4}(1.161)} \\ &= 107.6\end{aligned}$$

- So the proof load would need to induce a gross section stress of 107.6 ksi.