Fatigue

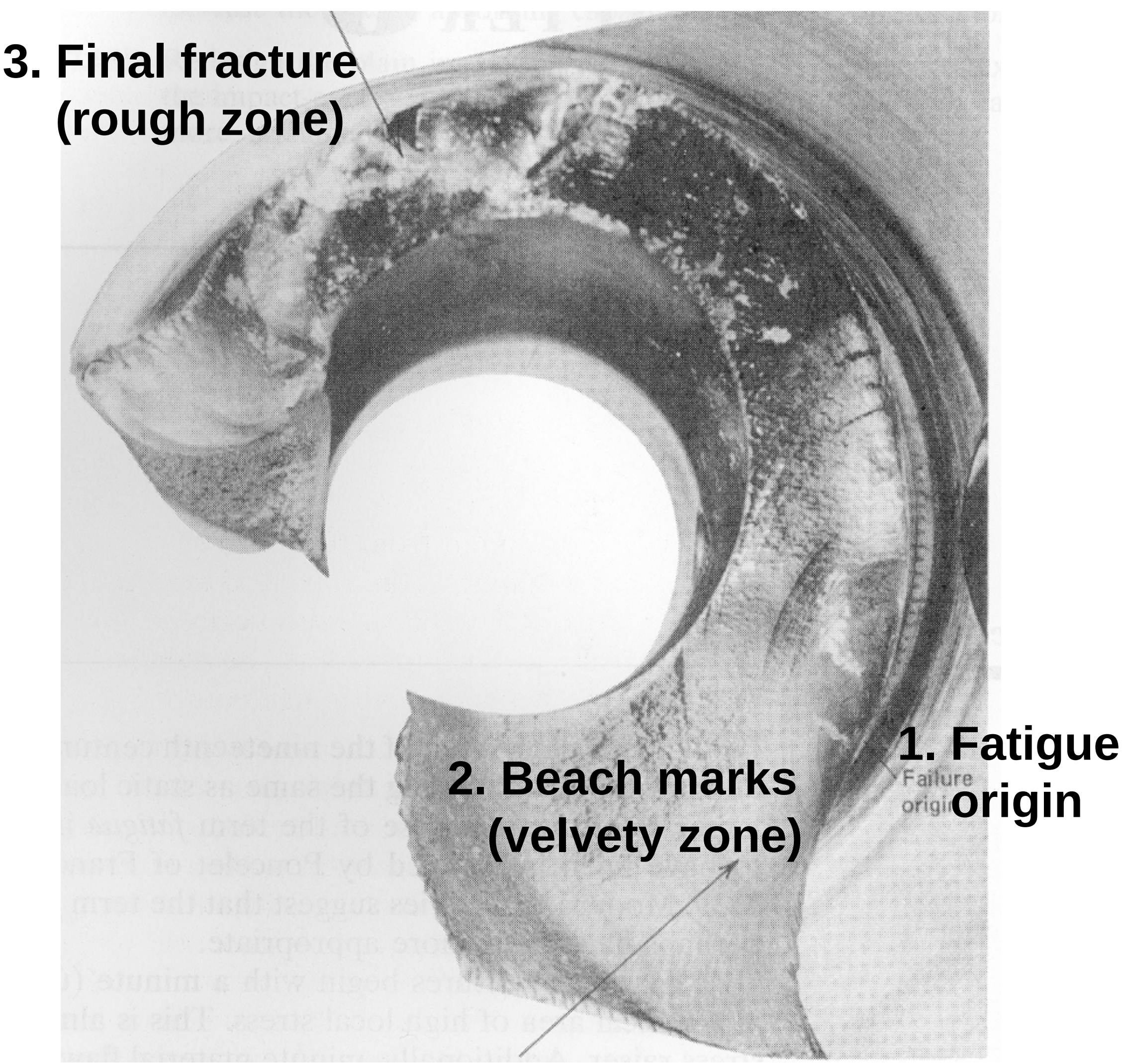
Term **fatigue** introduced by Poncelet (France) 1839
progressive fracture is more descriptive

1. Minute crack at critical area of high local stress
   (geometric stress raiser, flaws, preexisting cracks)

2. Crack gradually enlarges
   (creating “beach marks”)

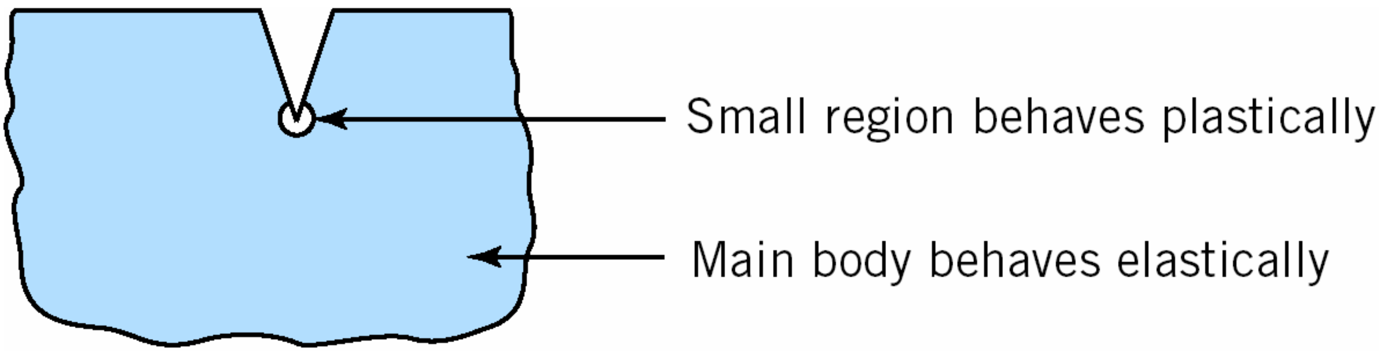
3. Final fracture
   (suddenly, when section sufficiently weakened)

Fatigue: no or only microscopic distortion
static failure: gross distortion



Fatigue

- Repeated plastic deformation
- Thousands/millions of microscopic yielding
  (far below conventional yield or elastic point)
- Highly localized plastic yielding
  (holes, sharp corners, threads, keyways, scratches, corrosion)



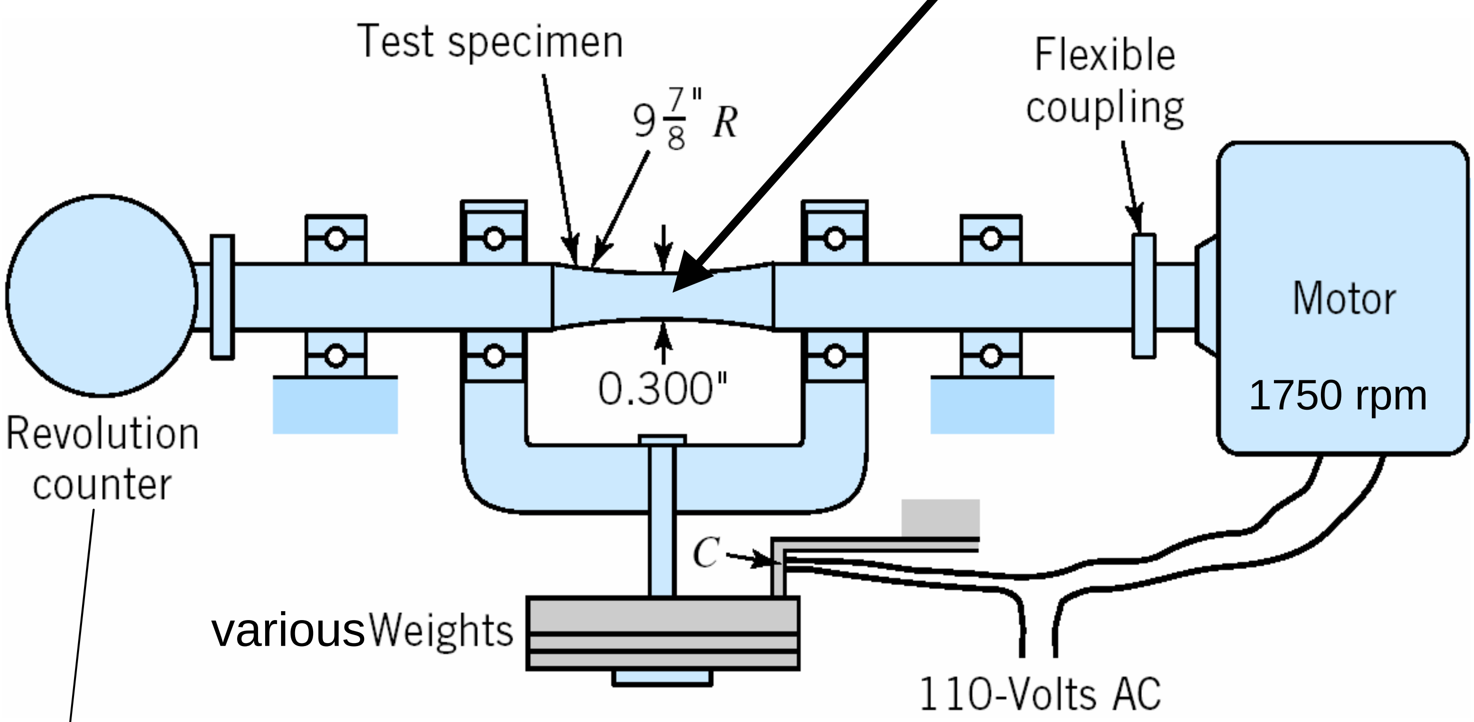
- **Strengthen vulnerable location** often as effective
  as choosing a stronger material
- (If local yielding is sufficiently minute
  strain-strengthen may stop the yielding)

Standard Fatigue Strength S_n'

Empirical data from *R.R. Moore fatigue test*
(Highly standardized and restricted conditions)

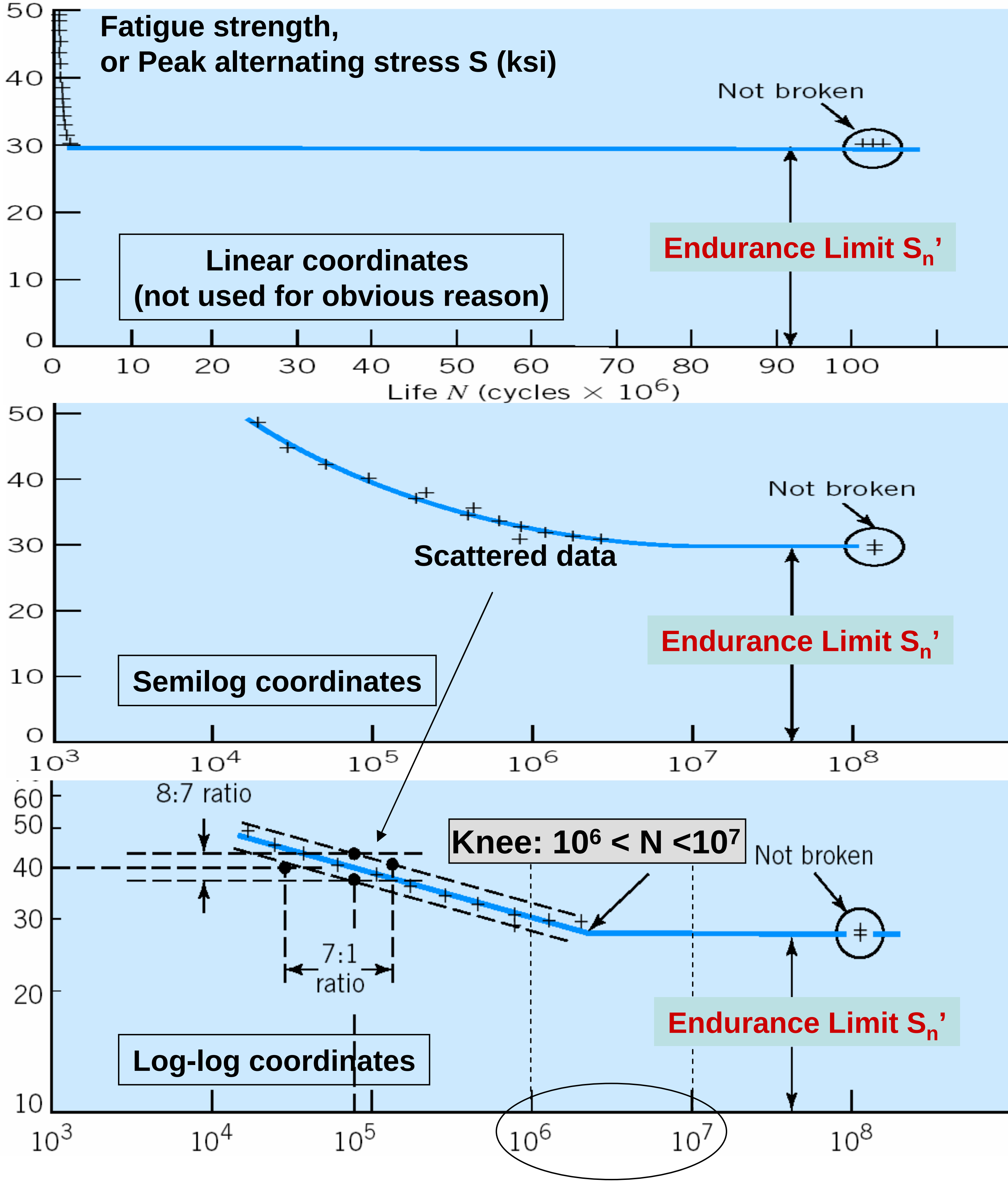
Rotating-beam fatigue-testing machine

Pure bending (zero traverse shear)



N cycles of tension-to-compression-to-tension

Standard Fatigue Strength S_n'



Ferrous materials: for life cycle $N > 10^6 \rightarrow \sigma < S_n$'

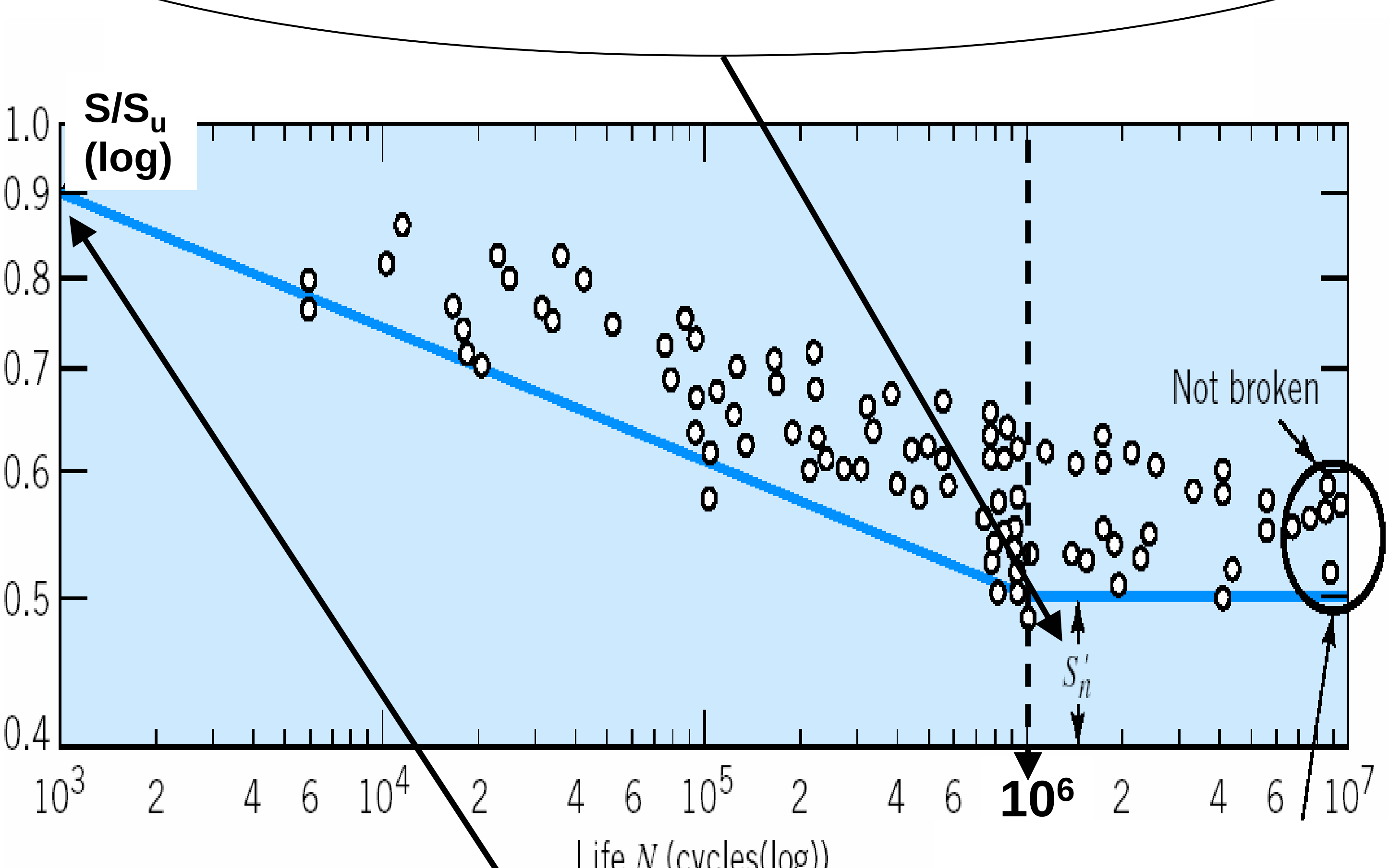
Fatigue Strength

S-N curve approximation for *steel*

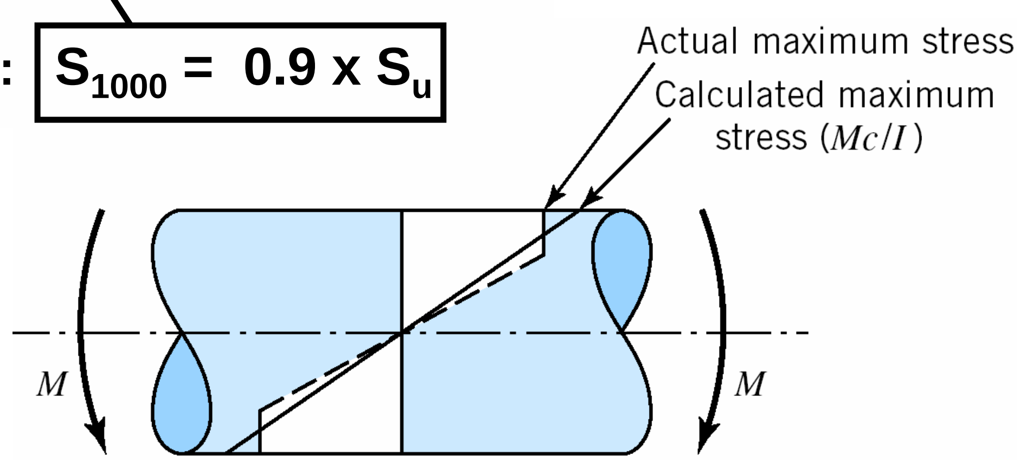
$S_n' = 0.5 \times S_u$ (0.4 x S_u for cast iron)

S_u/ksi=0.5 x H_B…**Brinell Hardness** (also Bhn)

Hence S_n' /ksi = 0.25 x H_B for H_B<400



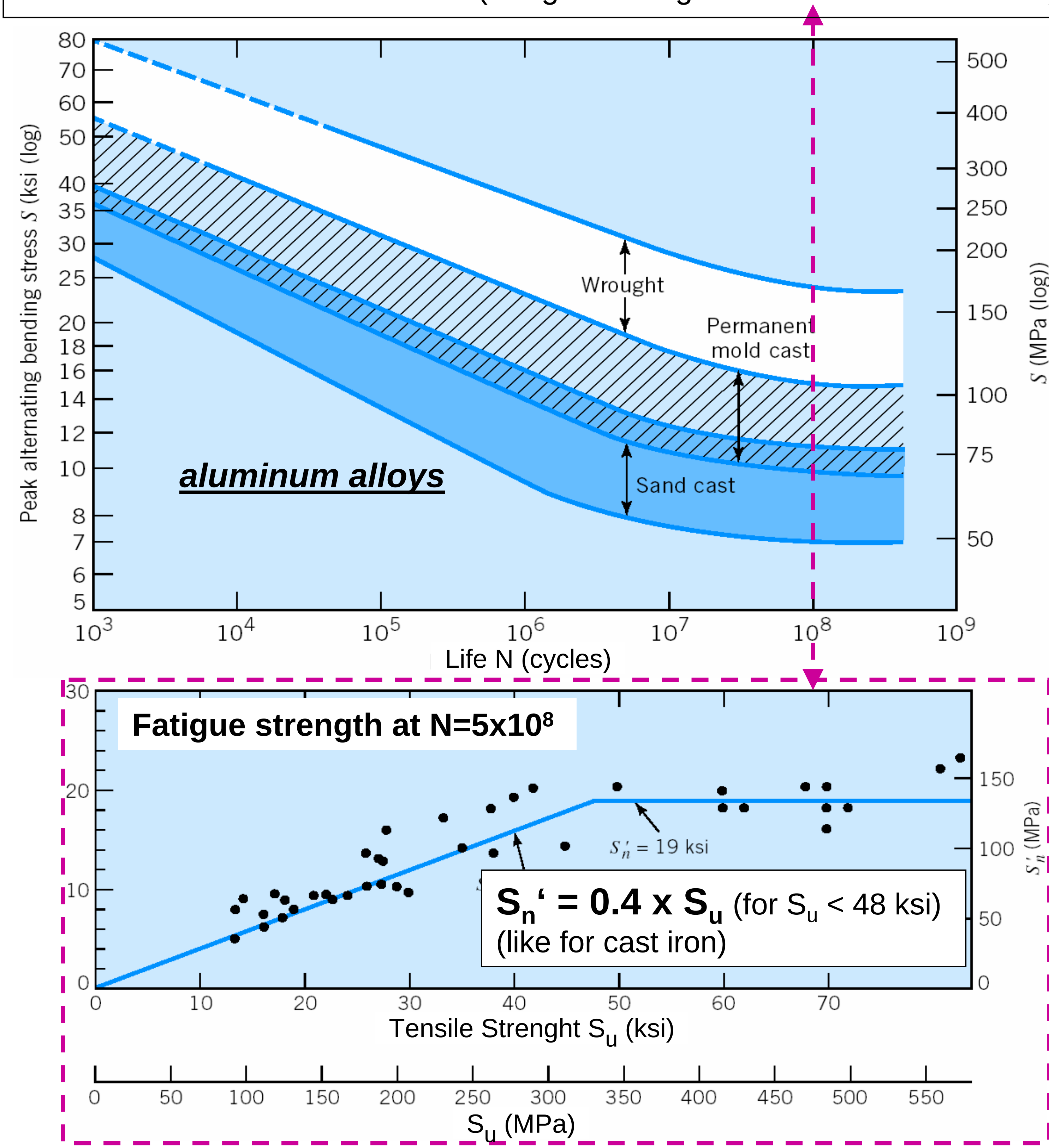
10^3-cycle fatigue: $S_{1000} = 0.9 \times S_u$



Endurance Limit

S-N curve for *nonferrous metals*

- **No Sharply defined knee and**
- **No True endurance limit** (Fatigue strength at N=**5×10^8** often used)



Endurance Limit

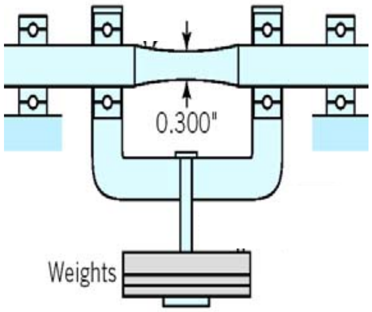
S-N curve approximation

Endurance limit

Steel	$S_n' = 0.5 \times S_u$	@ $N=10^6$
Titanium	$S_n' = 0.45 \ldots 0.6 \times S_u$	
Cast Iron	$S_n' = 0.4 \times S_u$	@ $N=10^8$
Aluminum		
Magnesium	$S_n' = 0.35 \times S_u$	
Nickel alloys	$S_n' = 0.35 \ldots 0.5 \times S_u$	
Cooper alloys	$S_n' = 0.25 \ldots 0.5 \times S_u$	

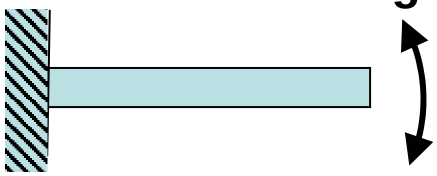
Endurance Limit

Rotating Bending (Moore testing)



maximum stresses **on surface**
weakest point → fatigue start

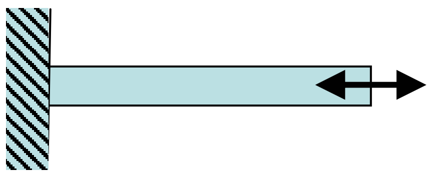
Reversed Bending (not rotating bending like in Moore testing)



maximum stresses **only @ top and bottom**
high probability not weakest point

Fatigue strength usually slightly greater
deliberately neglected → safe side

Reversed Axial Loading

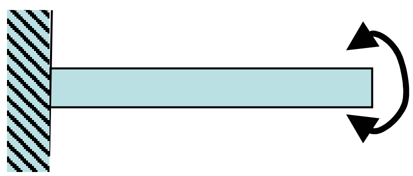


maximum stresses **entire cross section**
no reserve !

Fatigue strength about 10% less
eccentric loads about 20…30% less

} **C_G=0.7…0.9** *gradient factor*

Reversed Torsional Loading

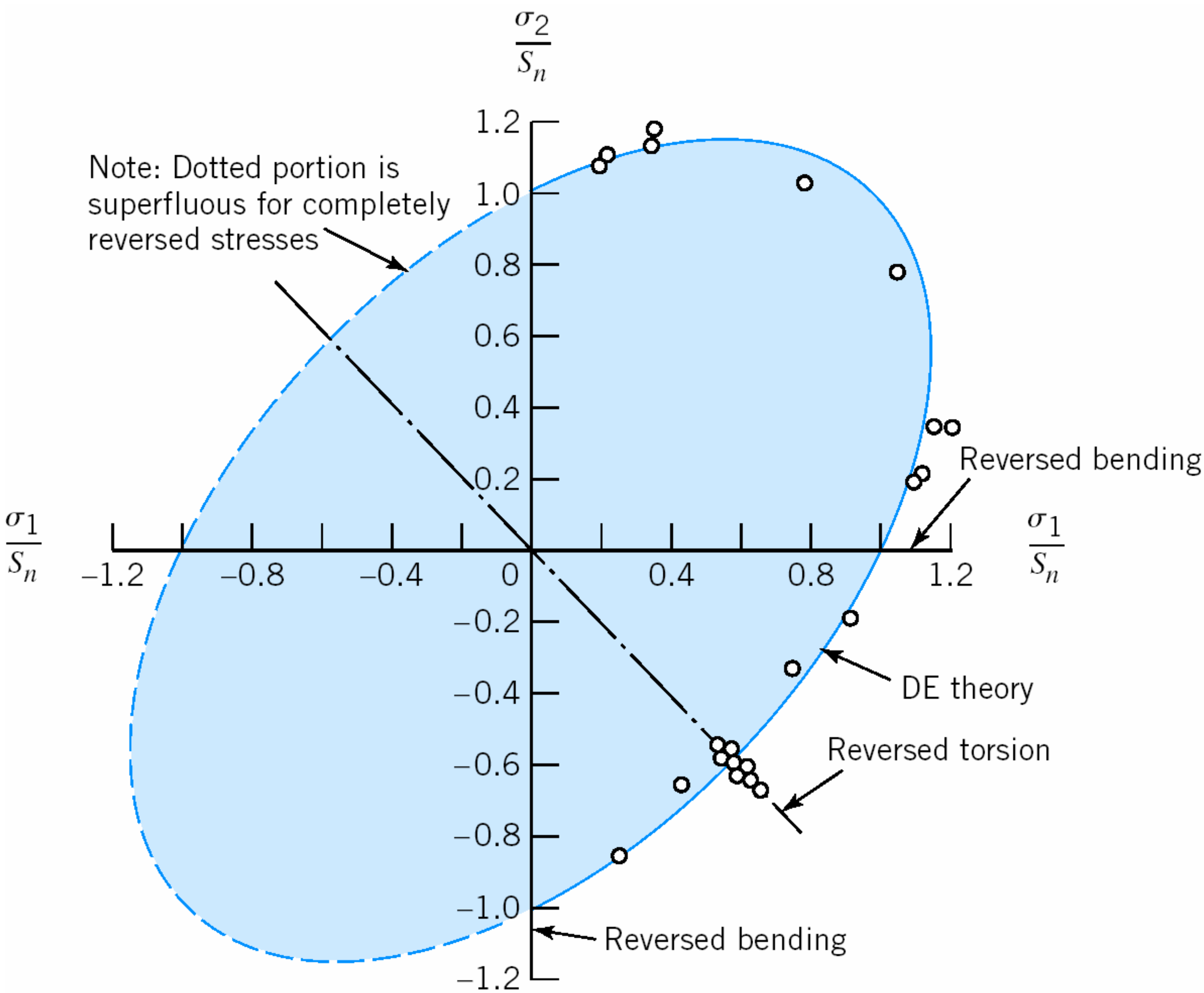


maximum stresses **on surface**
shear stresses → fatigue start

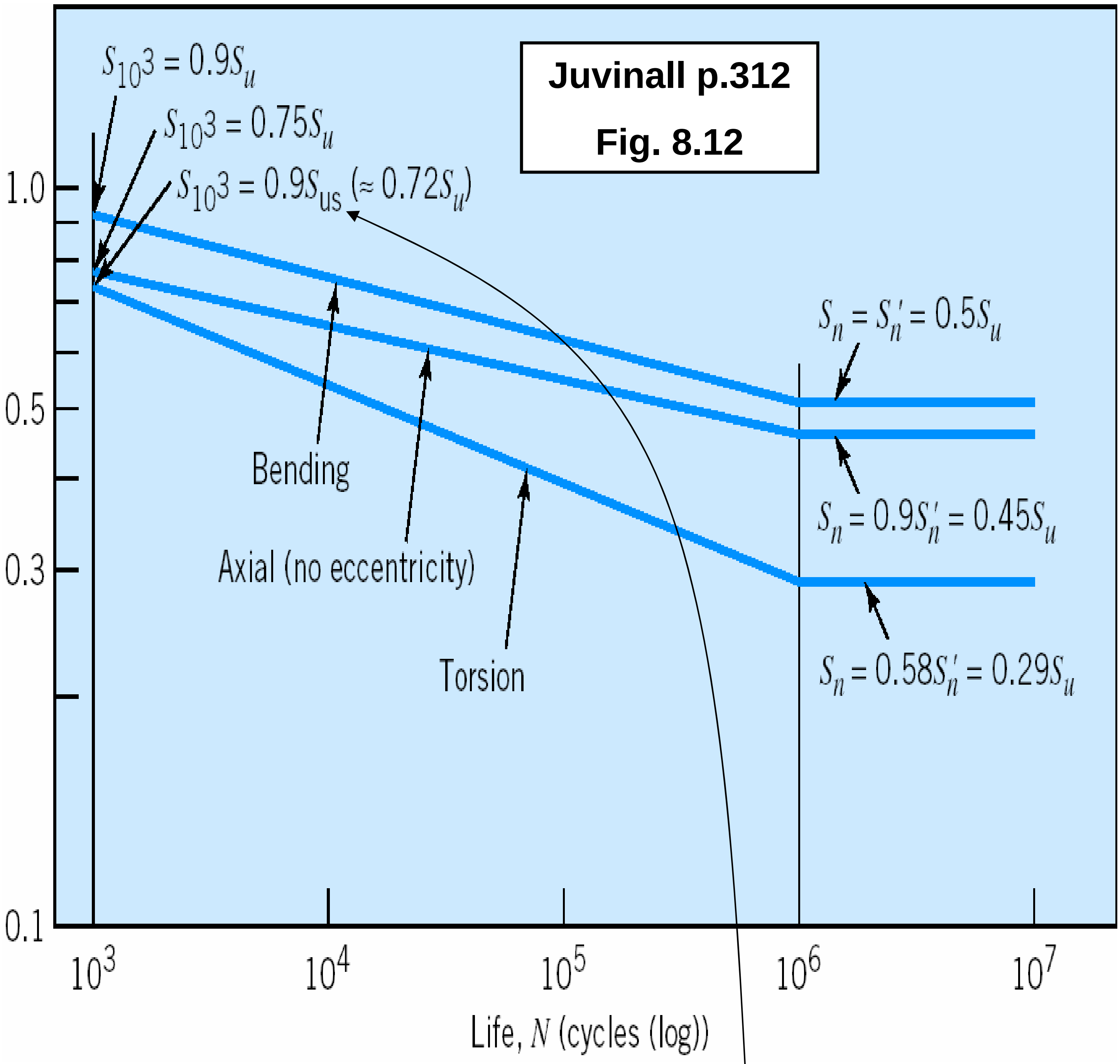
reversed biaxial stress
distortion energy theory → **58%**

} **C_L=0.58** *load factor*

Endurance Limit



Fatigue Strength



Steel
S_{us}=0.8 S_u

Other ductile material
S_{us}=0.7 S_u

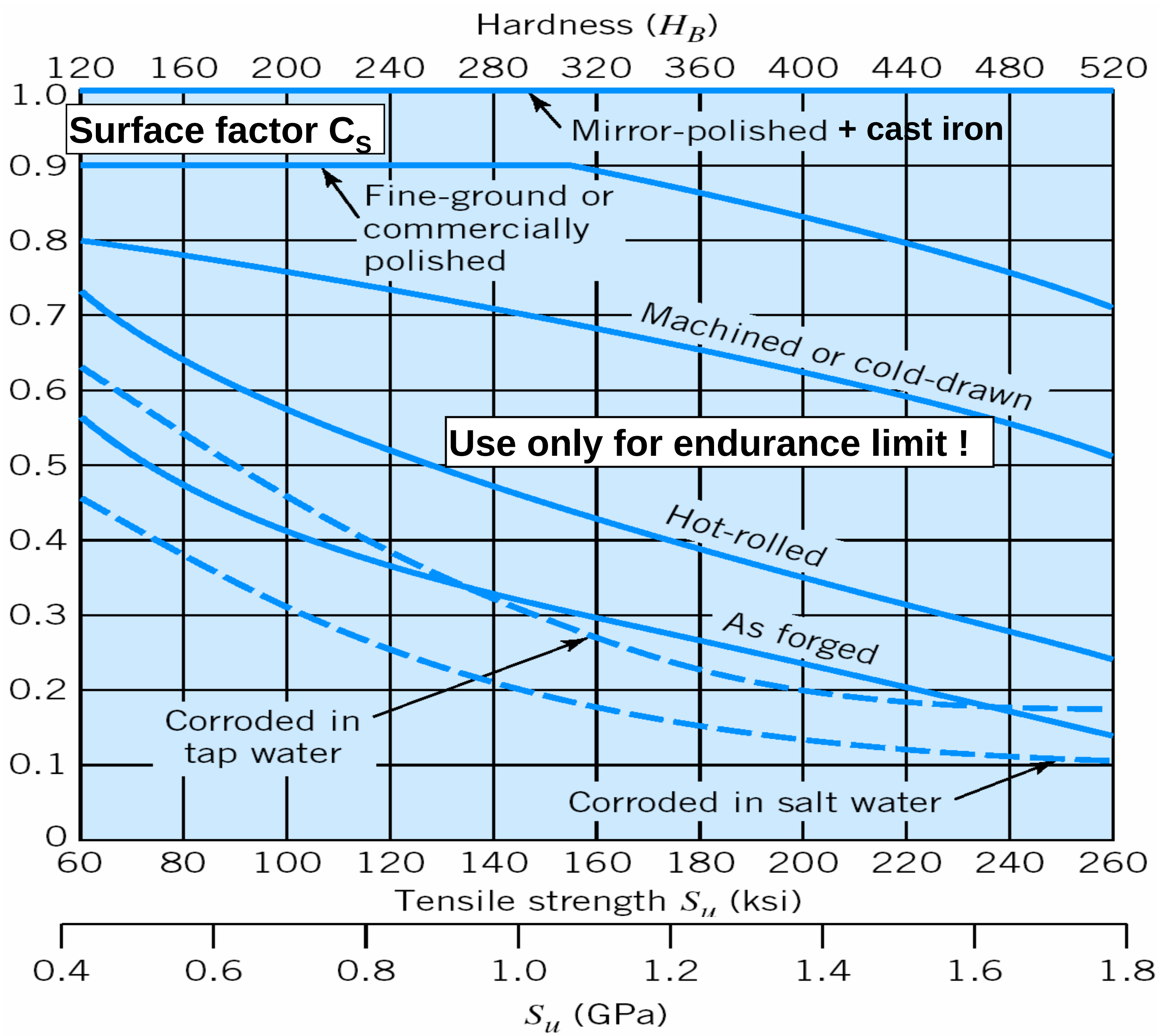
Fatigue Strength

Influence of *Surface*

So far special "mirror polish" surface (only in laboratory !)

Minimizes
1.) surface scratches (stress concentration)
2.) differences of surface & interior material
3.) residual stresses from finishing

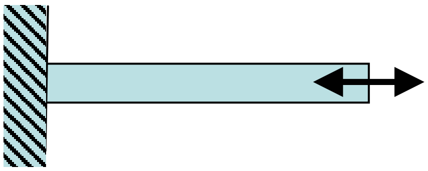
Commercial surfaces have **localized points** of **greater fatigue vulnerability.**



Fatigue Strength

Influence of ***Size***

Reversed Axial Loading

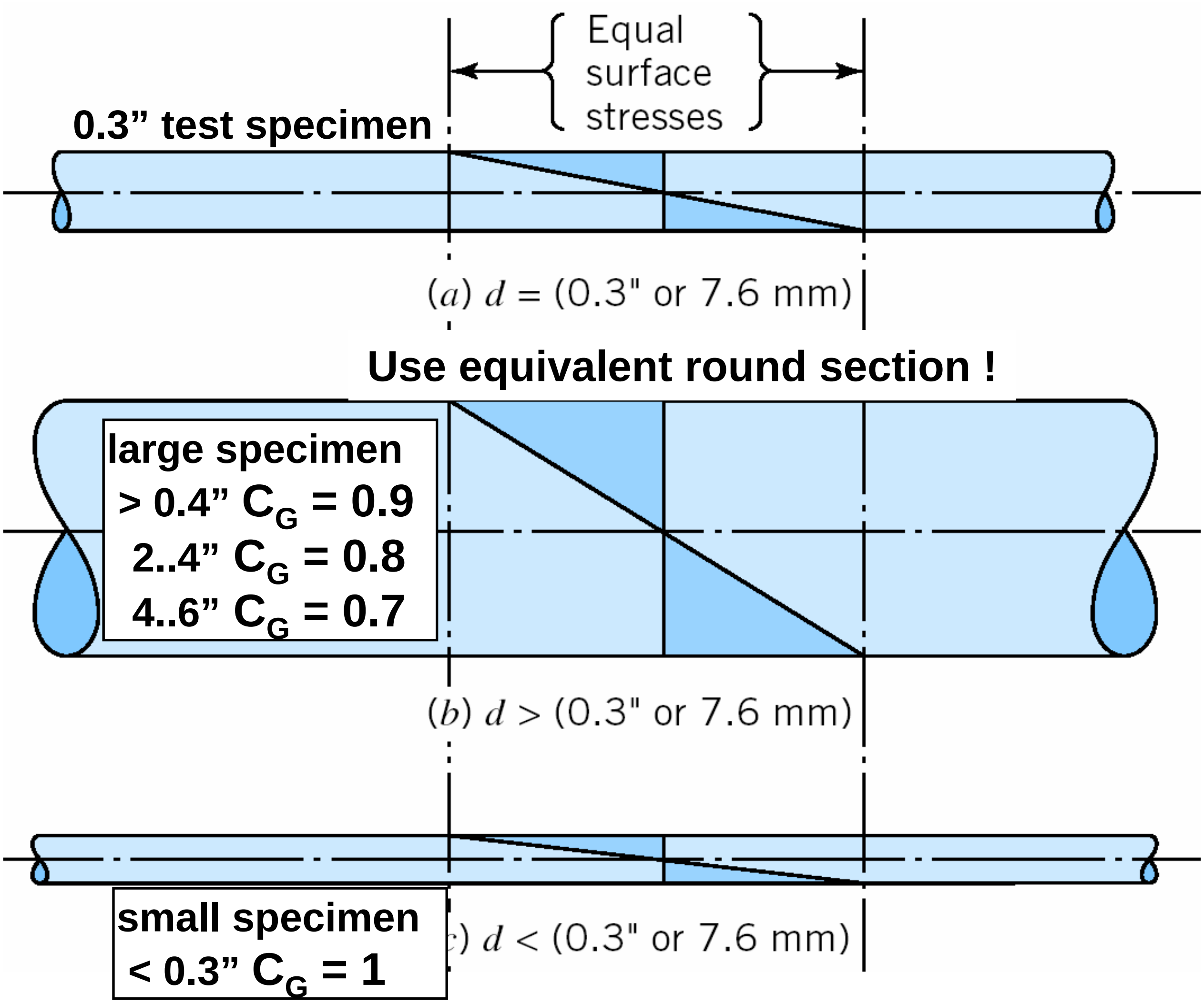


maximum stresses **entire cross section**
no reserve !

Fatigue strength about 10% less
eccentric loads about 20…30% less

C_G=0.7…0.9
gradient factor

Bending & Torsional Reversed Loading



Fatigue Strength

Summery use Table 8.1 Juvinall p.316

10^6-cycle strength (endurance limit)

$S_n = S_n' C_L C_G C_S$

S_n'… Moore endurance limit

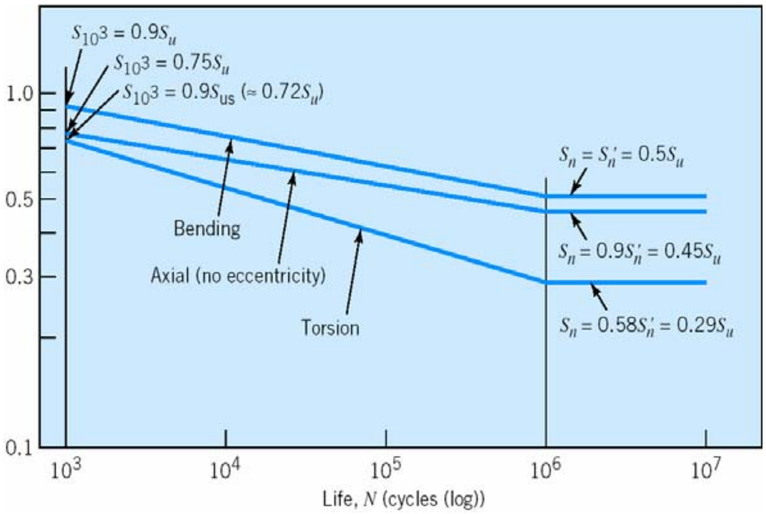
	Bending	Axial	Torsion
C_L *(load factor)*	**1**	**1**	**0.58**
C_G *(gradient factor)*			
< 0.4”	**1**	**0.7…0.9**	**1**
0.4”…2”	0.9	0.7…0.9	0.9
2”…4”		reduce -0.1	
4”…6”		reduce -0.2	
C_S *(surface factor)*		**see Fig. 8.13**	

1000-cycle strength

	Bending	Axial	Torsion
C_L *(load factor)*	**$0.9S_u$**	**$0.75S_u$**	**$0.9S_{us}$**

steel: $S_{us}=0.8S_u$

other ductile metals: $S_{us}=0.7S_u$

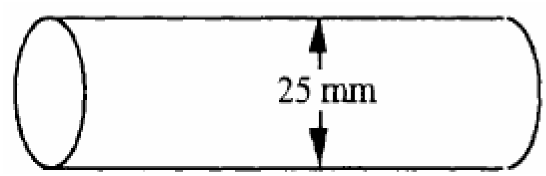


Example

P 8.18

Known: D=25mm, Su = 950MPa, S_y = 600MPa,
reversed axially loaded, steel, hot-rolled surface

Find: $S_n(2\text{x}10^5$ life cycles)



S_u = 950 MPa
S_y = 600 MPa

Endurance limit (10^6 cycle strength)

$S_n = S_n' C_L C_G C_s$

For axial,

$S_n' = 0.5S_u = 0.5(950) = 475$ MPa

$C_L = 1$

$C_G = 0.8$ (between 0.7 and 0.9)

$C_s = 0.475$

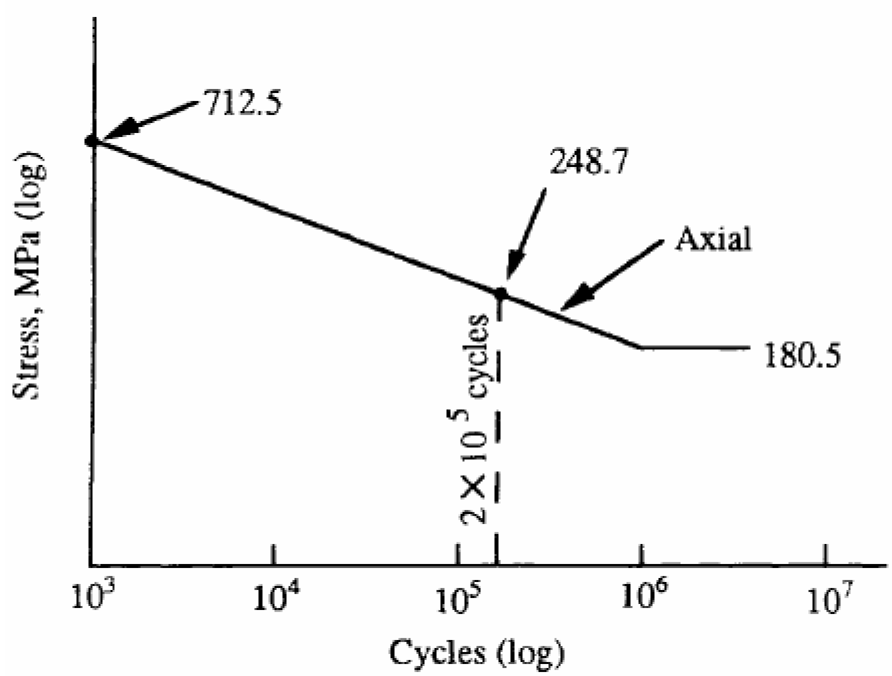
$S_n = (475)(1)(0.8)(0.475) = 180.5$ MPa

10^3 cycle strength

For axial,

$0.75S_u = 0.75(950) = 712.5$ MPa

S-N curves

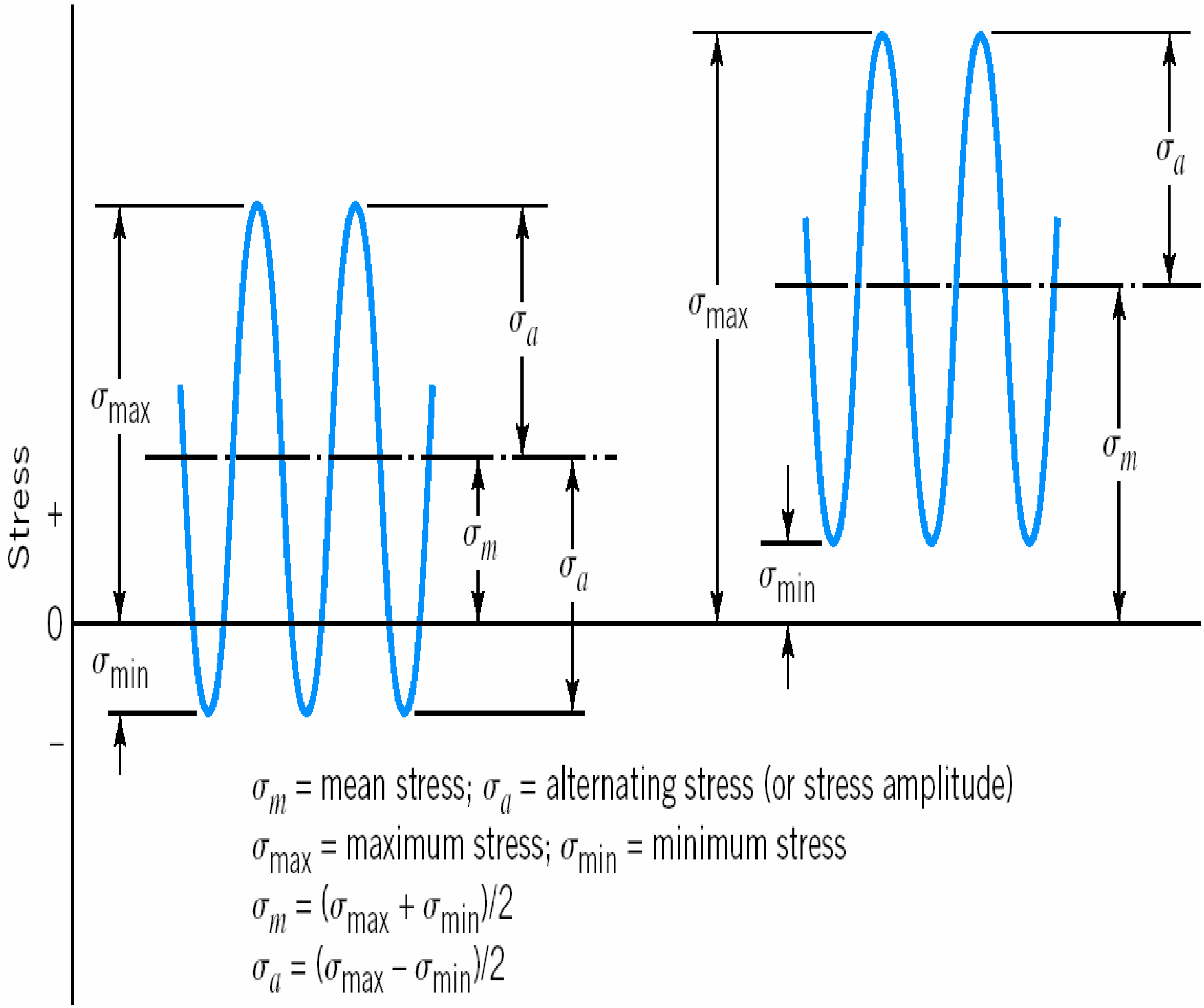


Fatigue Strength

Effect of ***mean stress***

Fluctuating stress = static stress + completely reversed stress

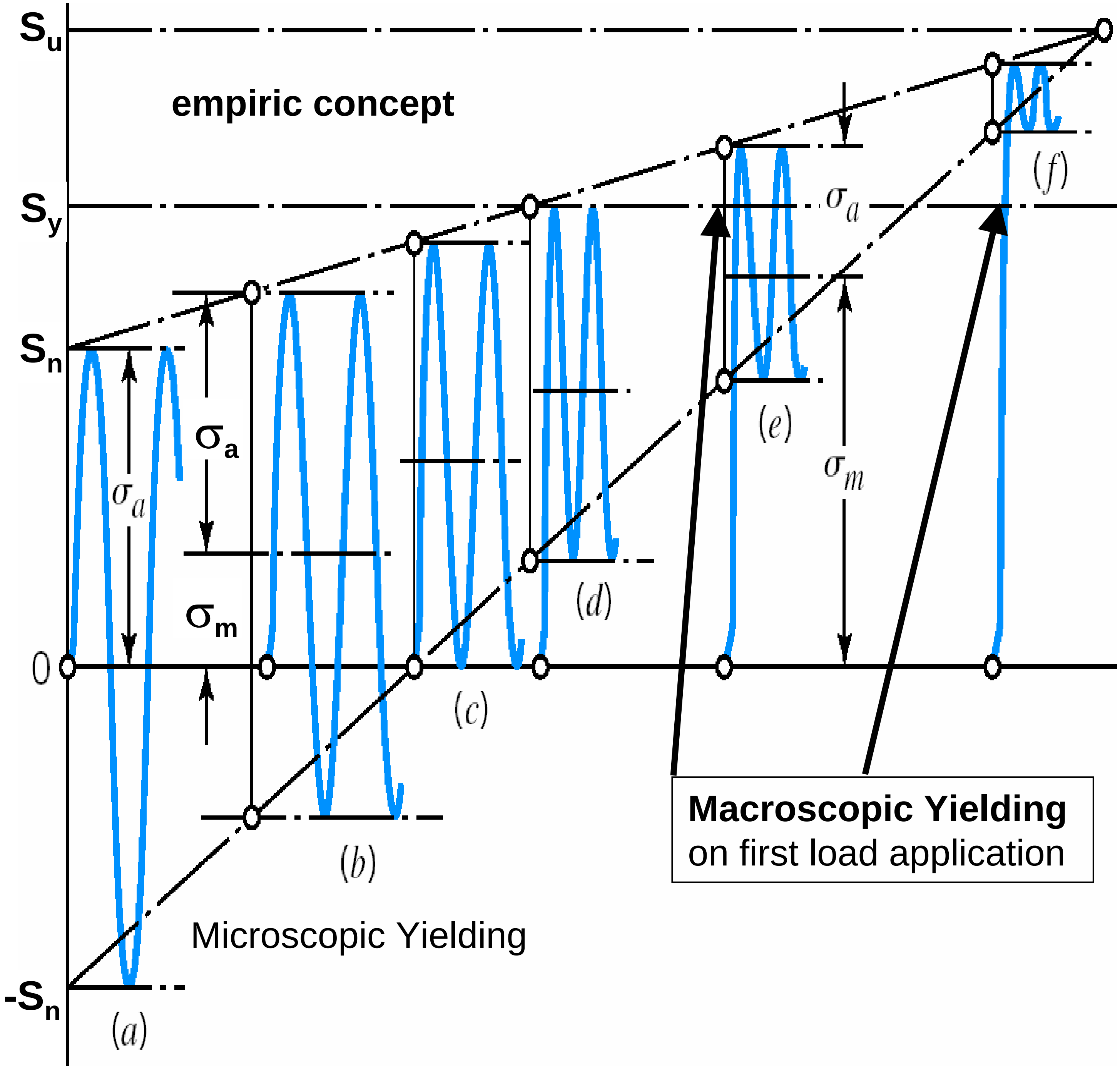
mean + alternating



Fatigue Strength

Effect of ***mean stress***

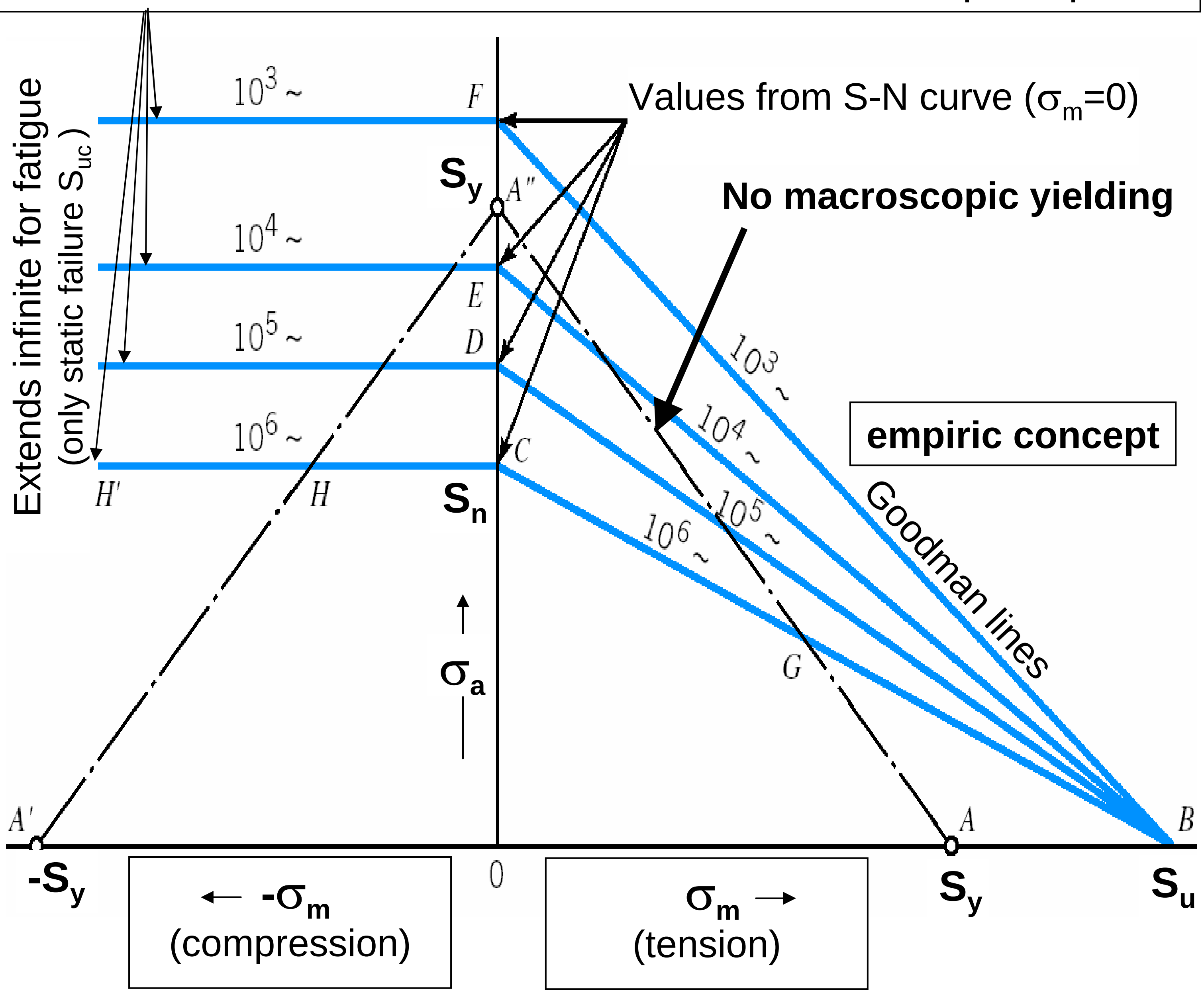
Static tensile stress *reduces amplitude* of reversed stress that can be superimposed



Fatigue Strength

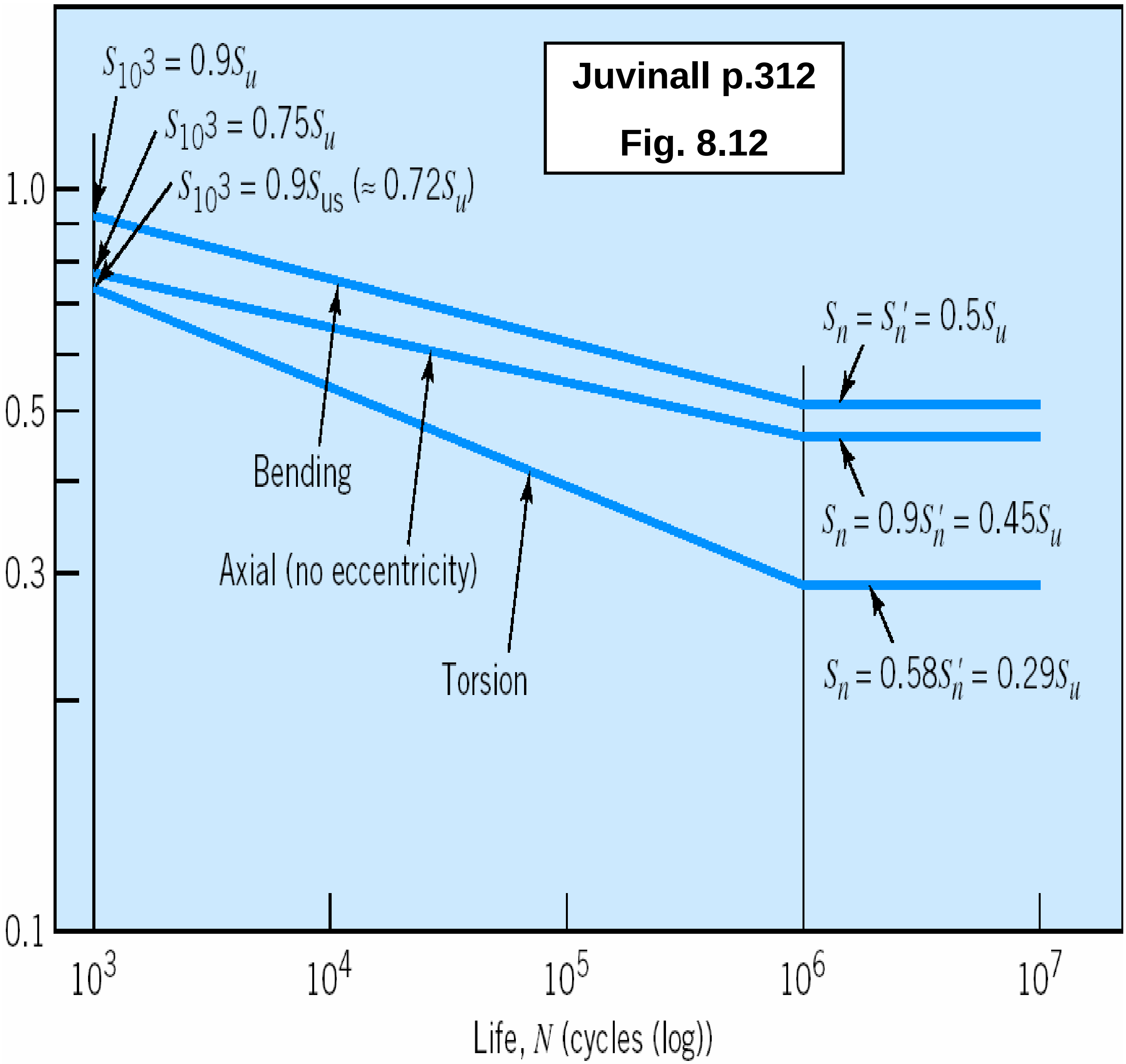
Effect of *mean stress*

Compressive mean stress *does not reduce amplitude*
that can be superimposed



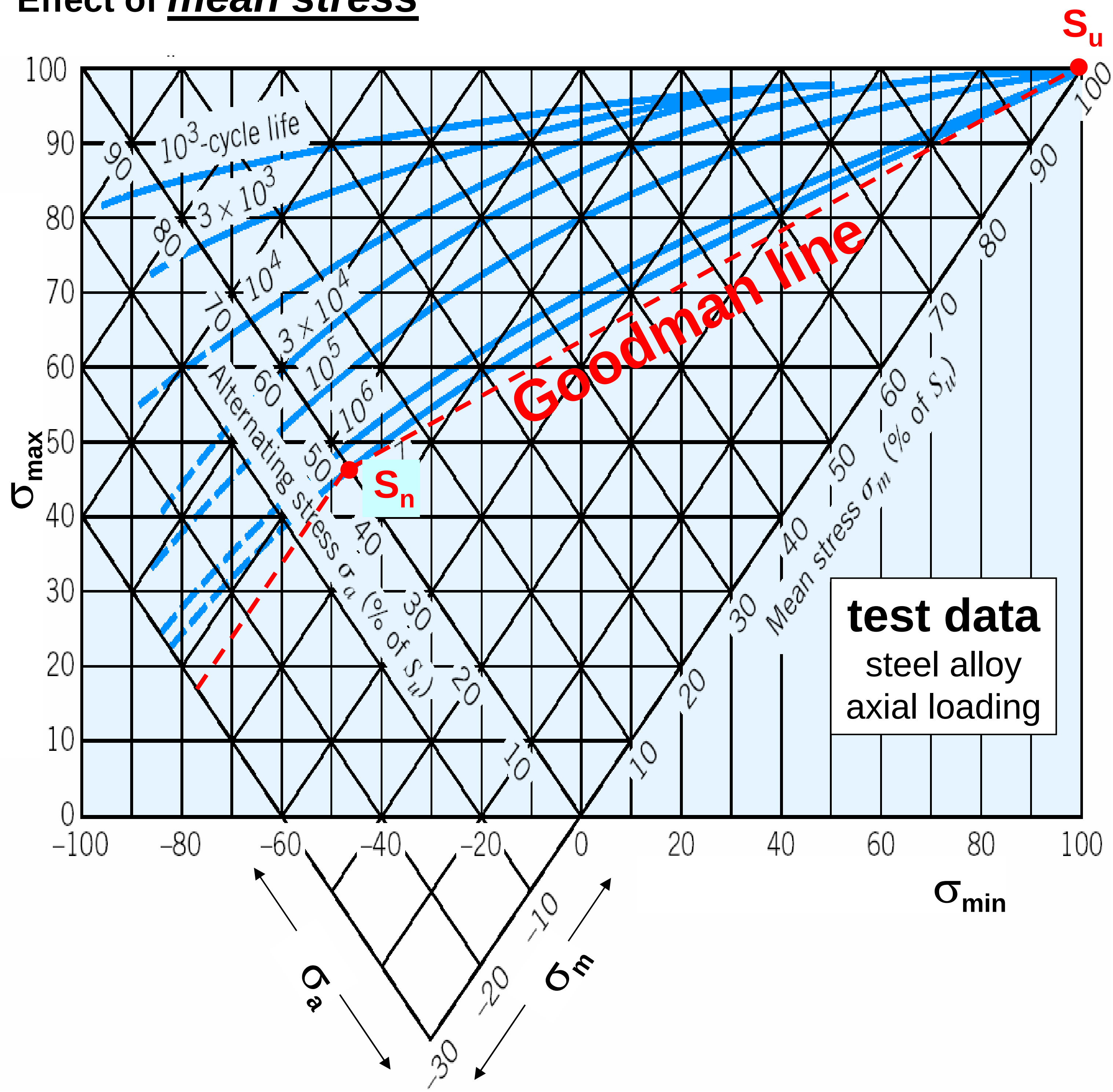
constant-life fatigue diagram
Juvinall p.318 Fig. 8.16

Fatigue Strength



Fatigue Strength

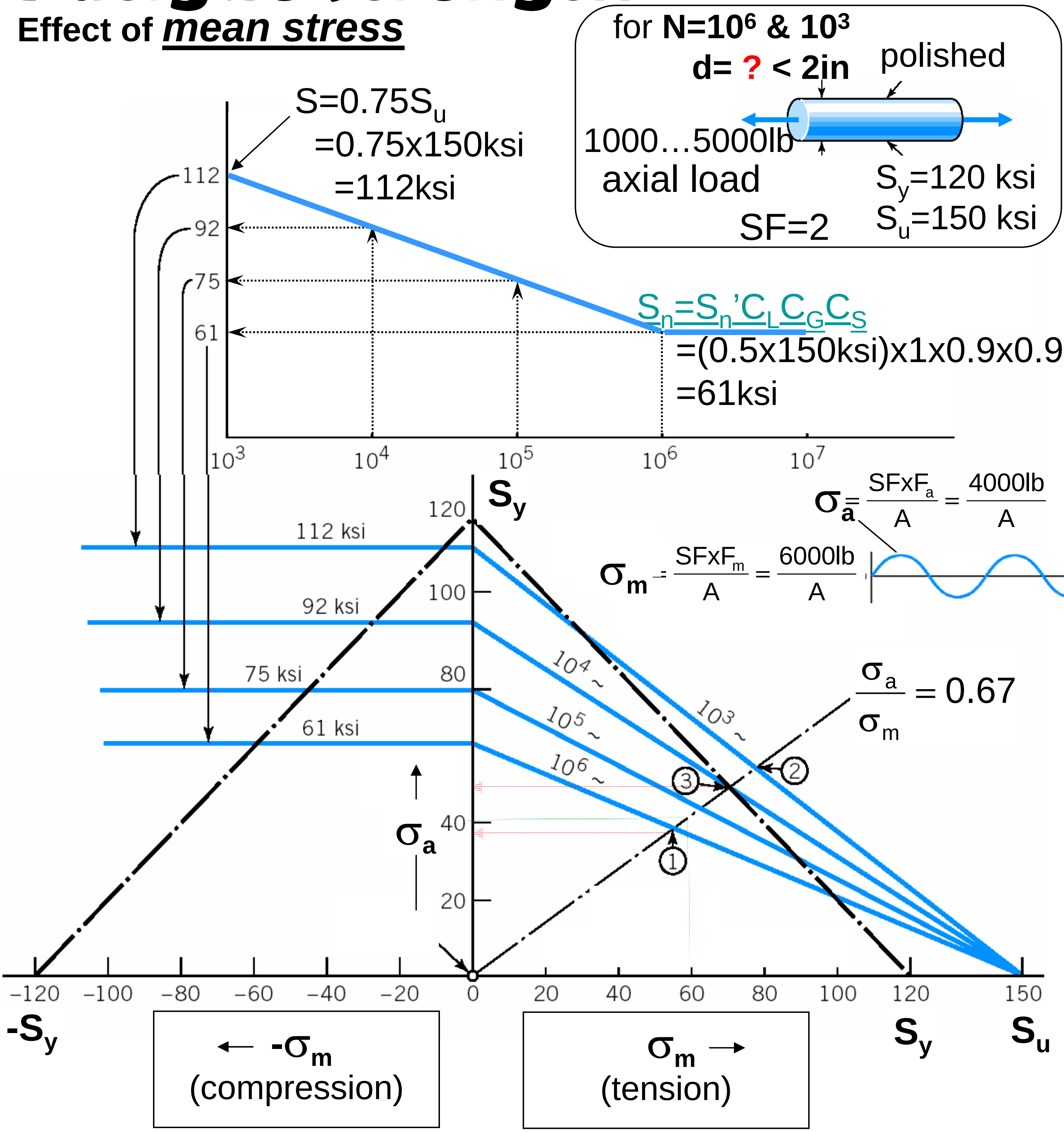
Effect of *mean stress*



Note: Brittle materials are usually on Goodman line

Fatigue Strength

Effect of *mean stress*

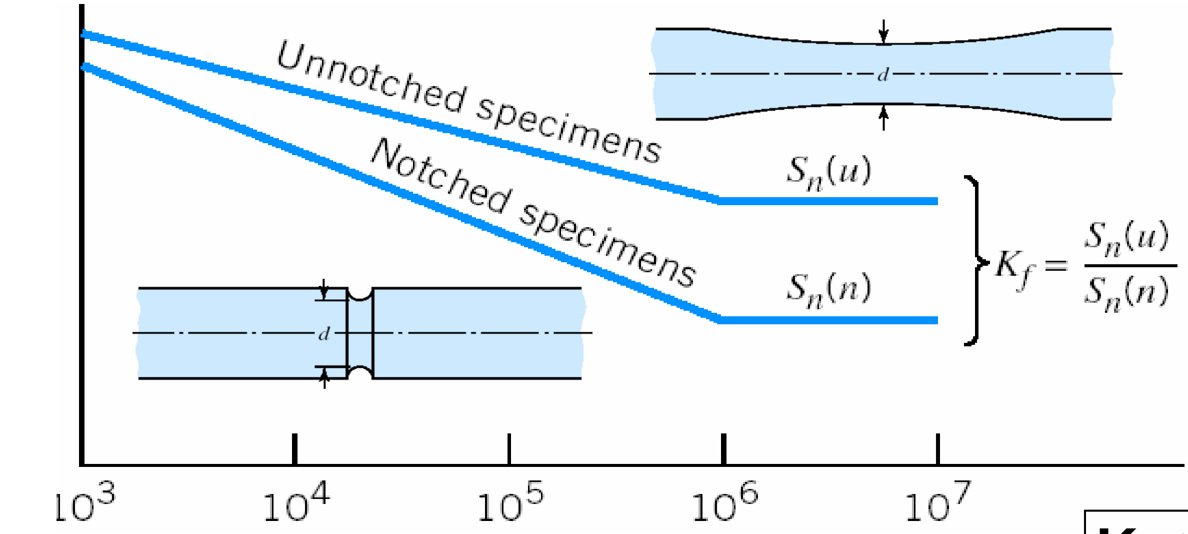


$\sigma_a(N=10^6)=38ksi \longrightarrow d=0.367in < 3/8\ in$

$\sigma_a(S_y)=48ksi \longrightarrow d=0.326in < 11/32in$

Fatigue Strength

Stress concentration

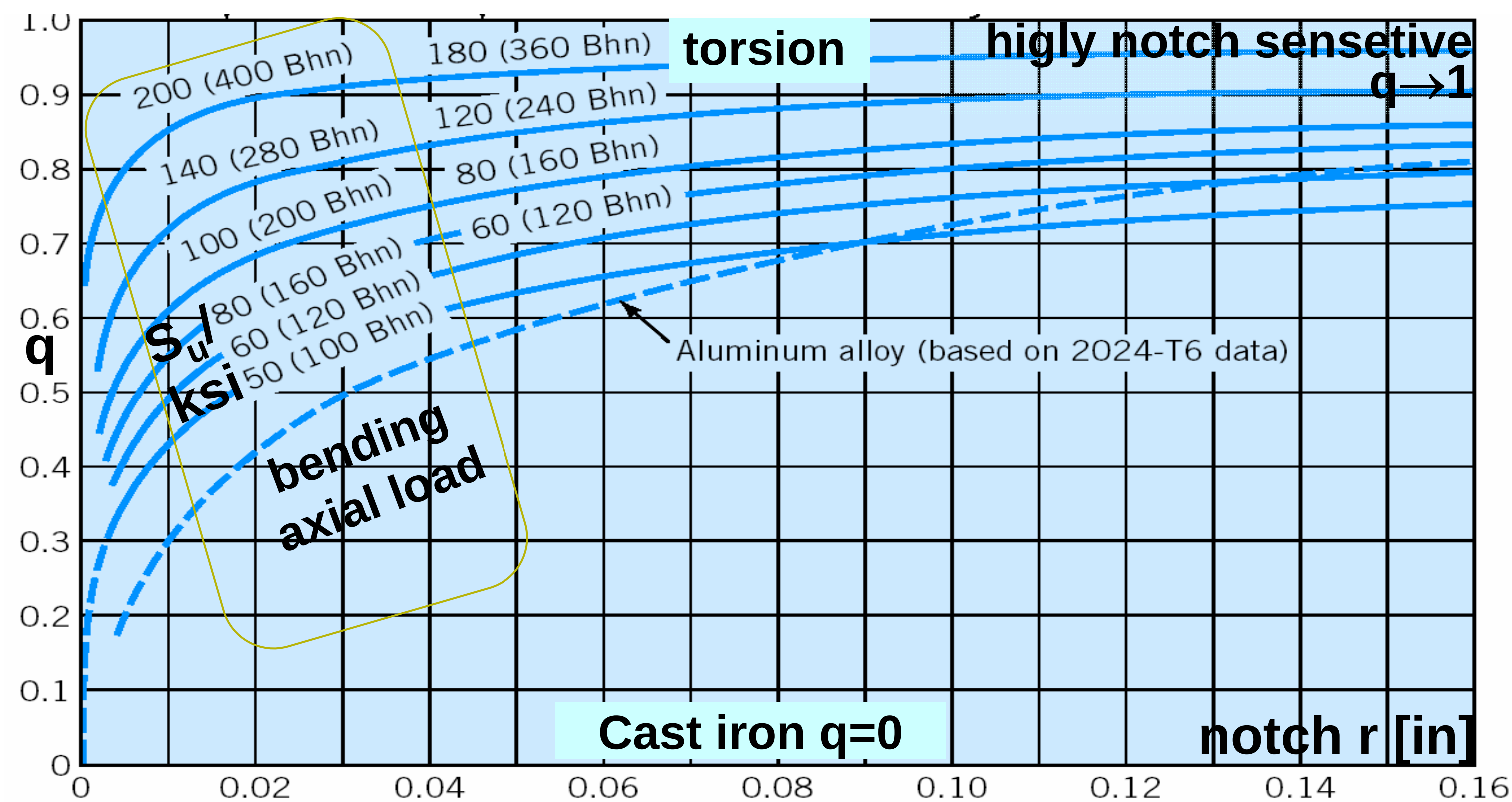


$K_f < K_t$

$$K_f = 1 + (K_t - 1) \cdot q$$

q…sensitivity factor

geometric or theoretic factor



Apply K_f to mean stress σ_m and to alternating stress σ_a