

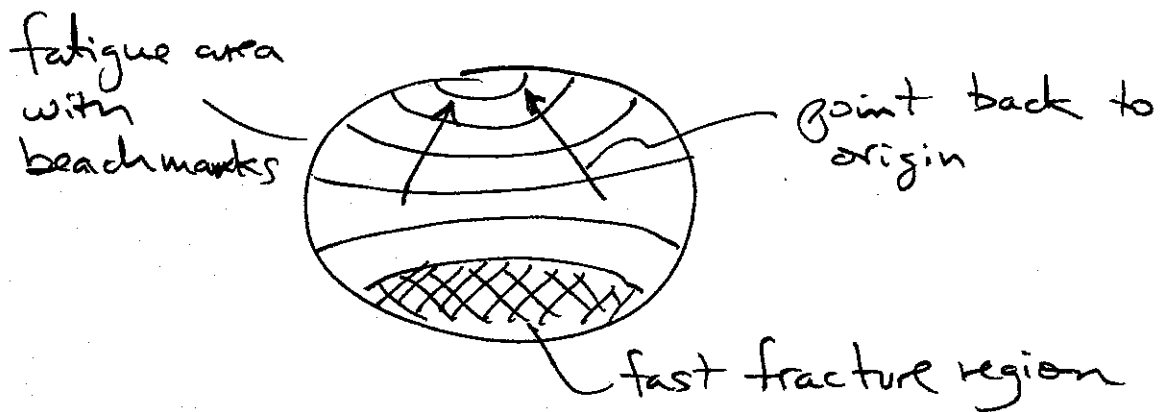
# FATIGUE

fatigue - tendency to fracture as a result of cyclic application of stress

macrofractography of fatigue failures -

"beachmarks" - "clam shell markings"

- reflect periods of crack growth / arrest



fatigue loads induced via -   
 - fixed stress limits   
 - fixed displacement limits

stress controlled  $\Rightarrow$  S-N diagrams

S-N diagrams - generated with load controlled coupon tests

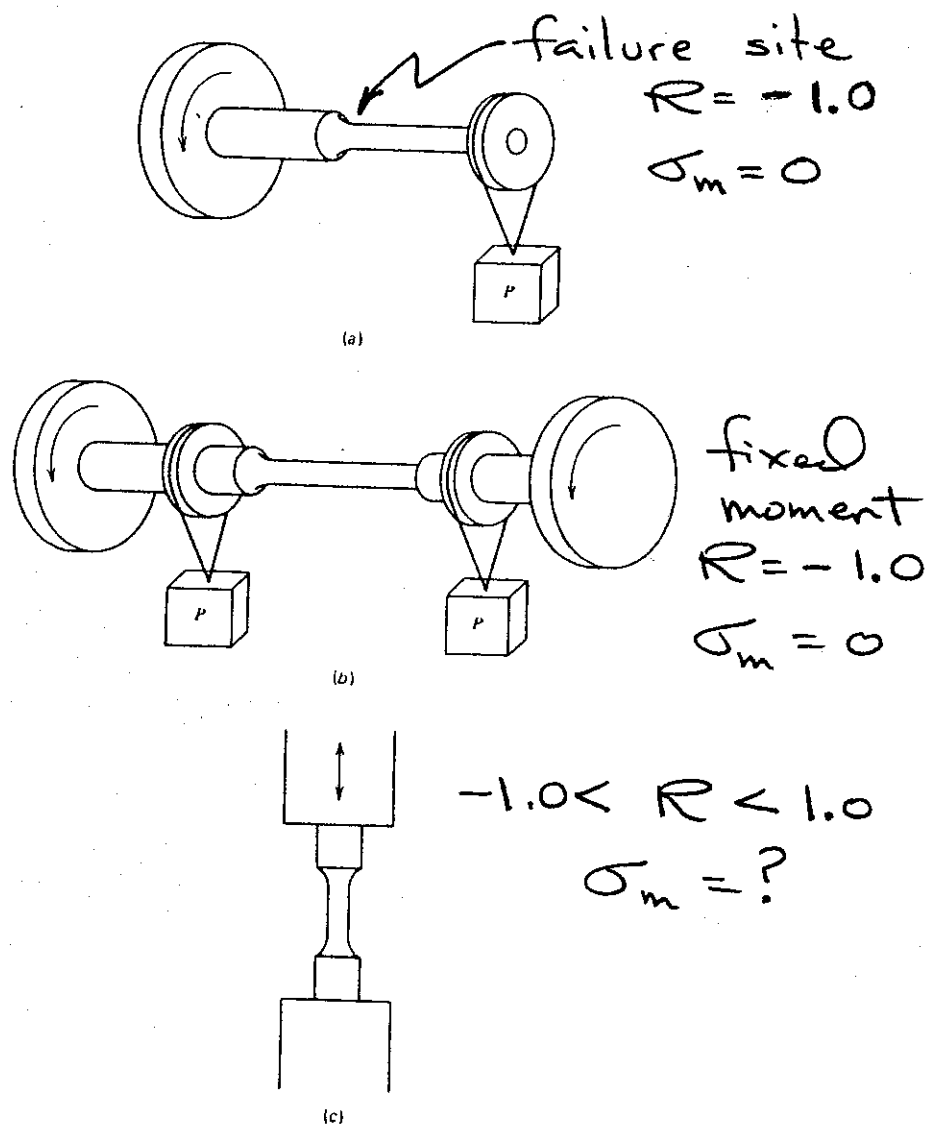
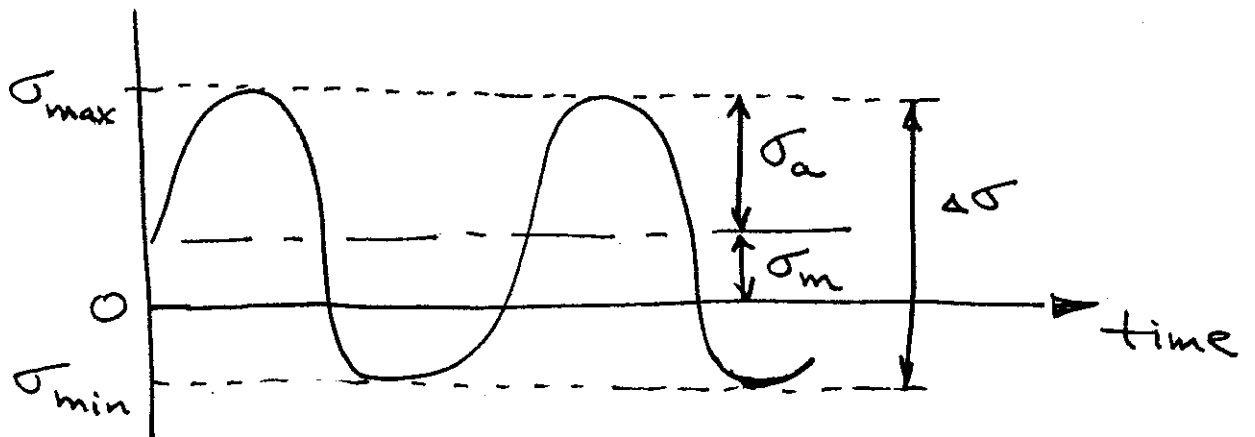


FIGURE 12.7 Various loading configurations used in fatigue testing. (a) Single-point loading, where bending moment increases toward the fixed end; (b) beam loading with constant moment applied in gage section of sample; (c) pulsating tension or tension-compression axial loading.



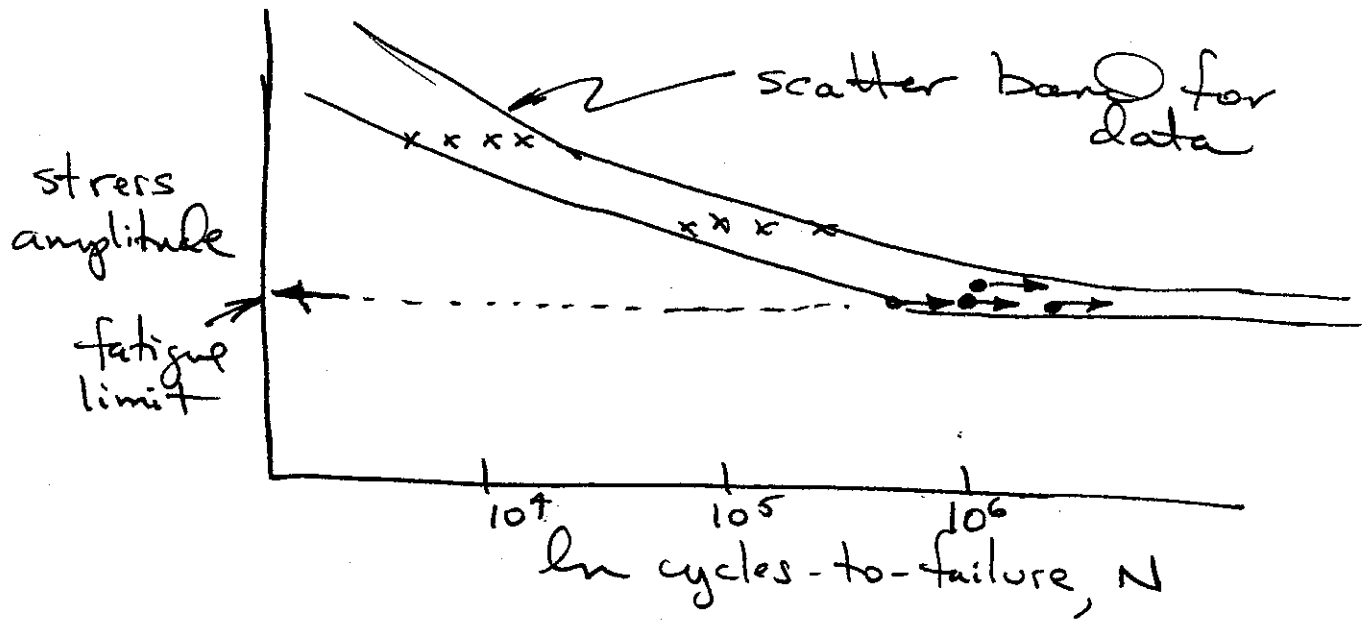
$$\Delta\sigma - \text{stress range} = \sigma_{\max} - \sigma_{\min}$$

$$\sigma_a - \text{stress amplitude} = \frac{\sigma_{\max} - \sigma_{\min}}{2}$$

$$\sigma_m - \text{mean stress} = \frac{\sigma_{\max} + \sigma_{\min}}{2}$$

$$R = \frac{\sigma_{\min}}{\sigma_{\max}}$$

S-N curves determined using a constant  $R$ ,  $f$  - vary  $\sigma_a$  (use multiple specimens @ a given  $\sigma_a$ )



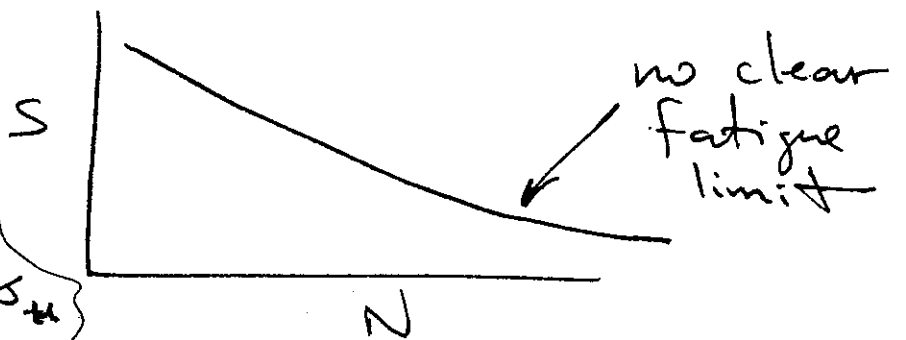
for steels — above schematic would

estimate of  
 $\sigma_e = 0.4 - 0.5 \sigma_u$

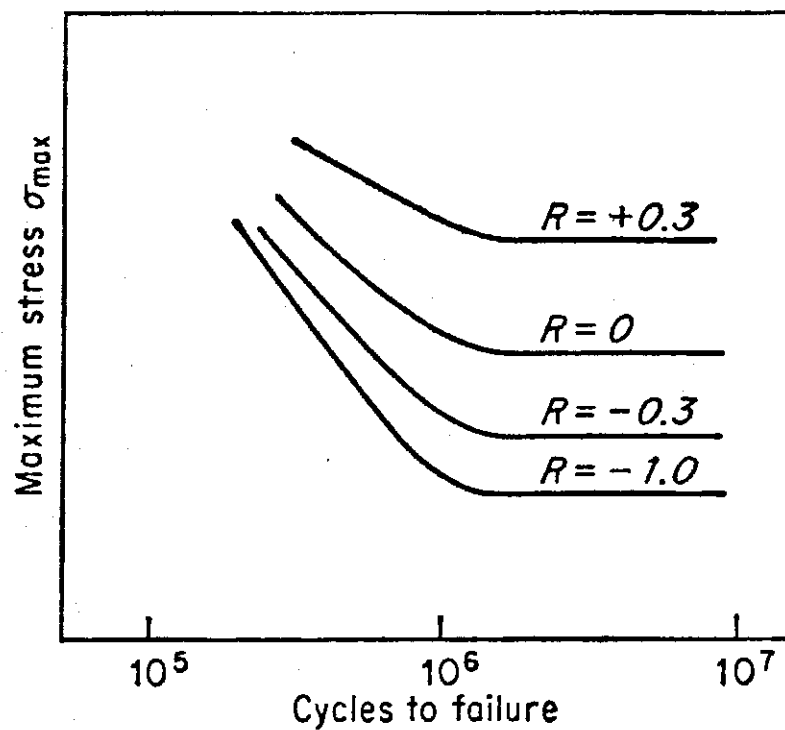
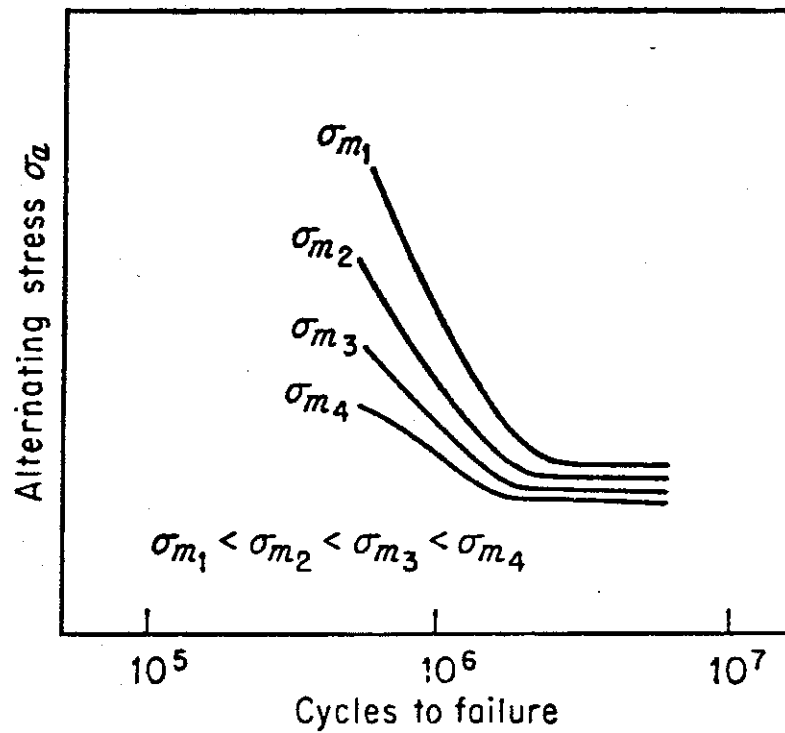
generally be observed with an "endurance" or "fatigue" limit being achieved by  $10^6$  cycles

for Al  
 @  $10^7$  cycles alloys

estimate of  
 $\sigma_e \approx 0.3 \text{ to } 0.35 \sigma_u$



# Mean Stress Effects



generally one of three methods are used to account for  $\sigma_a$  &  $\sigma_m$  in fatigue limit design:

(1) Goodman relation -

$$\sigma_a = \sigma_{fat} \left( 1 - \frac{\sigma_m}{\sigma_u} \right)$$

(2) Gerber relation -

$$\sigma_a = \sigma_{fat} \left[ 1 - \left( \frac{\sigma_m}{\sigma_u} \right)^2 \right]$$

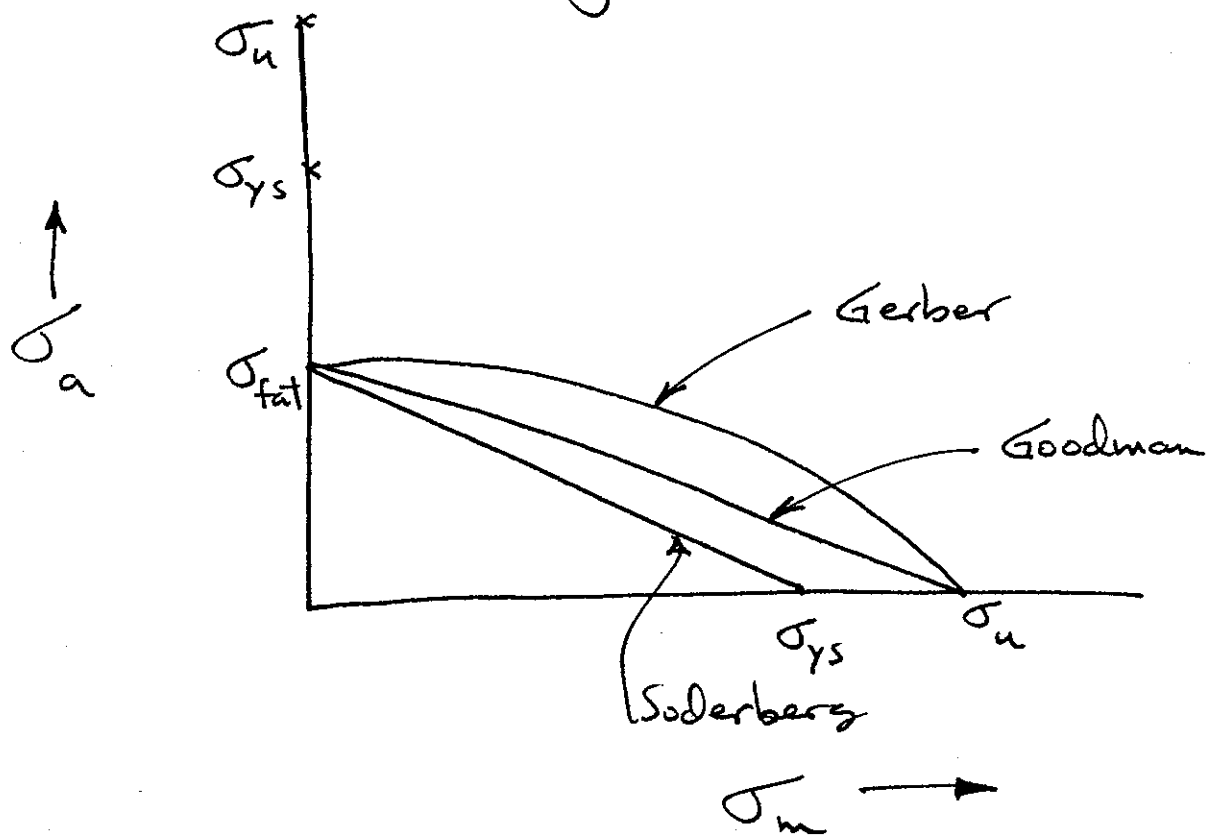
(3) Soderberg relation -

$$\sigma_a = \sigma_{fat} \left( 1 - \frac{\sigma_m}{\sigma_{ys}} \right)$$

where:

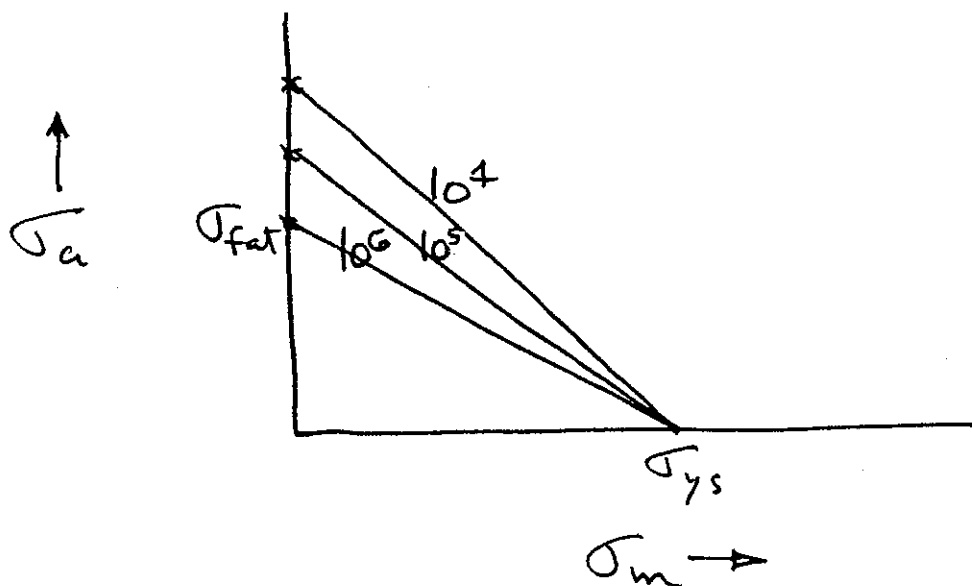
$\sigma_{fat}$  - fatigue strength or endurance limit for fully reversed loading ( $\sigma_m = 0$ )

These relations plot as shown:



actual data generally fall between Goodman & Gerber lines

for lifetimes other than  $10^6$  can modify Goodman diagram:



# Factors That Affect Fatigue Life

## Surface Effects

- most cracks initiate at surfaces  $\Rightarrow$  improving surface finish delays crack initiation & improves fatigue life
- scratches, machining marks, fillets, surface roughness, etc., should be scrutinized
- surface treatments can be used to improve fatigue life:

### mechanical treatments

shot peening

cold rolling

grinding, polishing

### thermal treatments

flame hardening

induction hardening

surface coatings

case hardening

nitriding

plating

\* Compressive residual stresses are often present with these surface treatments. These stresses retard crack initiation

### S-N, E-N Design Approaches

- use strong, hard materials for high cycle fatigue applications
- use ductile metals for low cycle fatigue applications
- avoid stress concentrations resulting in high  $K_t$  levels
- Goodman diagram, Manson-Coffin, other design methods employed

**TABLE 12.1 Fatigue Endurance Limit of Selected Engineering Alloys**

Material	Condition	$\sigma_{ts}$ MPa (ksi)	$\sigma_{ys}$ MPa (ksi)	$\sigma_f$ MPa (ksi)
<i>Steel Alloys<sup>a</sup></i> (Endurance limit based on $10^7$ cycles)				
1015	Cold drawn—0%	455 (66)	275 (40)	240 (35)
1015	Cold drawn—60%	710 (102)	605 (88)	350 (51)
1040	Cold drawn—0%	670 (97)	405 (59)	345 (50)
1040	Cold drawn—50%	965 (140)	855 (124)	410 (60)
4340	Annealed	745 (108)	475 (69)	340 (49)
4340	Q & T (204°C)	1950 (283)	1640 (238)	480 (70)
4340	Q & T (427°C)	1530 (222)	1380 (200)	470 (68)
4340	Q & T (538°C)	1260 (183)	1170 (170)	670 (97)
HY140	Q & T (538°C)	1030 (149)	980 (142)	480 (70)
D6AC	Q & T (260°C)	2000 (290)	1720 (250)	690 (100)
9Ni-4Co-0.25C	Q & T (315°C)	1930 (280)	1760 (255)	620 (90)
300M	—	2000 (290)	1670 (242)	800 (116)
<i>Aluminum Alloys<sup>b</sup></i> (Endurance limit based on $5 \times 10^8$ cycles)				
1100-0		90 (13)	34 (5)	34 (5)
2014-T6		483 (70)	414 (60)	124 (18)
2024-T3		483 (70)	345 (50)	138 (20)
6061-T6		310 (45)	276 (40)	97 (14)
7075-T6		572 (83)	503 (73)	159 (23)
<i>Titanium Alloys<sup>c</sup></i> (Endurance limit based on $10^7$ cycles)				
Ti-6Al-4V		1035 (150)	885 (128)	515 (75)
Ti-6Al-2Sn-4Zr-2Mo		895 (130)	825 (120)	485 (70)
Ti-5Al-2Sn-2Zr-4Mo-4Cr		1185 (172)	1130 (164)	675 (98)
<i>Copper Alloys<sup>c</sup></i> (Endurance limit based on $10^8$ cycles)				
70Cu-30Zn Brass	Hard	524 (76)	435 (63)	145 (21)
90Cu-10Zn	Hard	420 (61)	370 (54)	160 (23)
<i>Magnesium Alloys<sup>c</sup></i> (Endurance limit based on $10^8$ cycles)				
HK31A-T6	—	215 (31)	110 (16)	62-83 (9-12)
AZ91A	—	235 (34)	160 (23)	69-96 (10-14)

<sup>a</sup>*Structural Alloys Handbook*, Mechanical Properties Data Center, Traverse City, MI, 1977.

<sup>b</sup>*Aluminum Standards and Data 1976*, The Aluminum Association, New York, 1976. (See source for restrictions on use of data in design.)

<sup>c</sup>*Materials Engineering* 94(6) (Dec. 1981), Penton/IPC Publication, Cleveland, OH.