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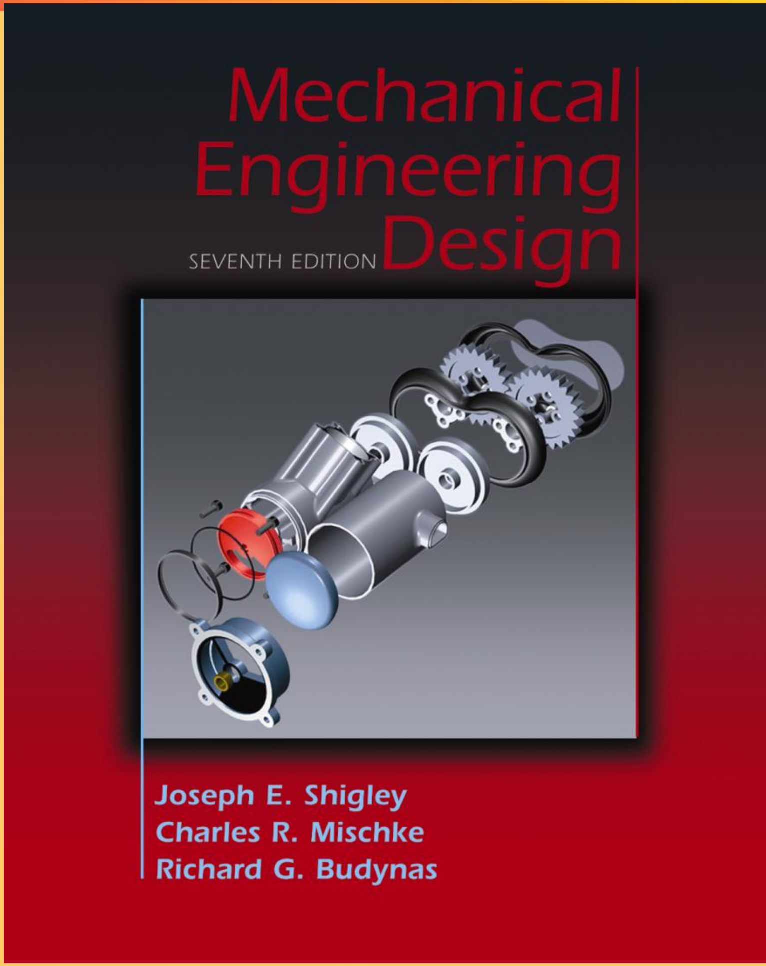
Chapter 6

Failures Resulting from Static Loading

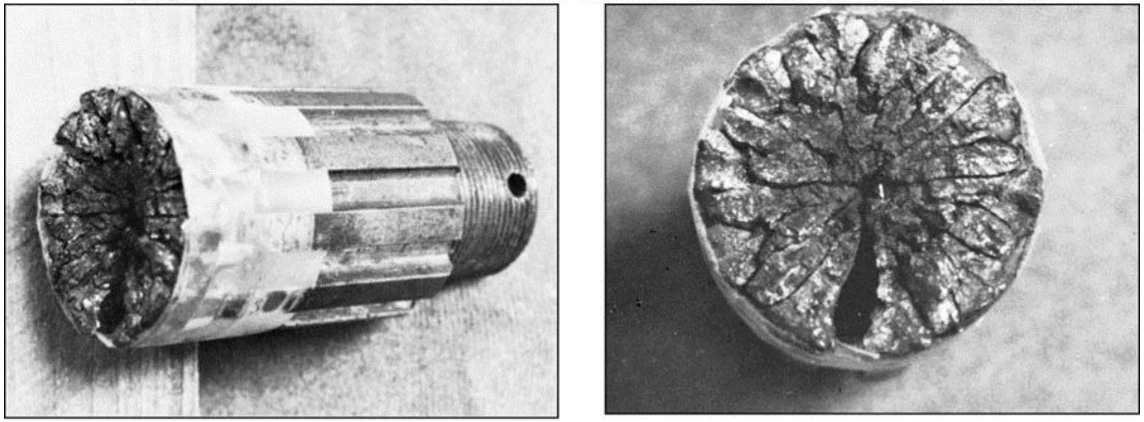
Mechanical Engineering Design

Seventh Edition

Shigley • Mischke • Budynas



Failure Examples



(*a*) (*b*)

Fig. 6.1 (a) Failure of a truck drive-shaft spline due to corrosion fatigue. (b) Direct end view of failure.

Fig. 6.2 Fatigue failure of an automotive cooling fan due to vibrations caused by a defective water pump.

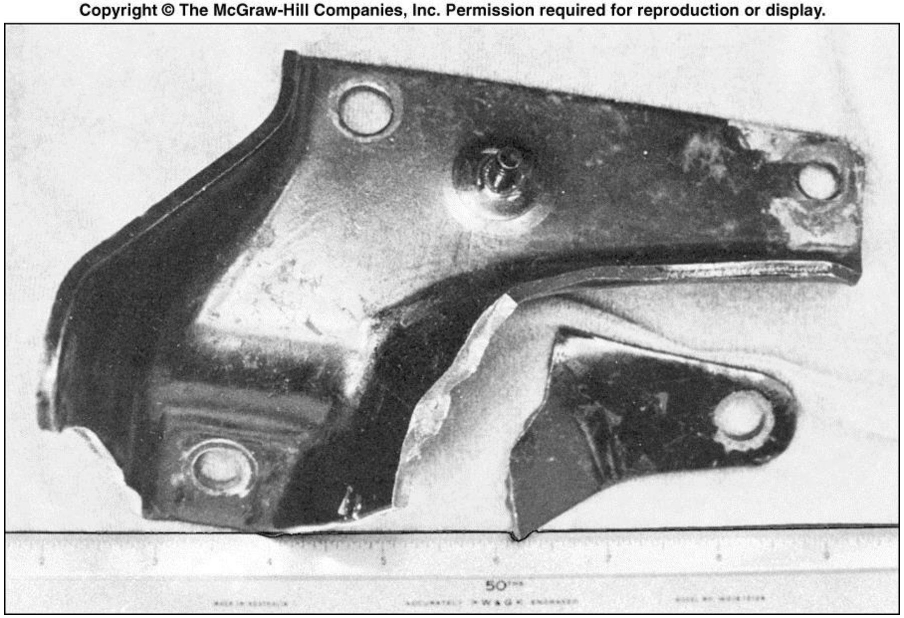


Fig. 6.3 Typical failure of a stamped steel alternator bracket after about 40000 km. The failure was probably due to residual stresses caused by the cold-forming operation. The high failure rate prompted the manufacturer to redesign the bracket as a die casting.

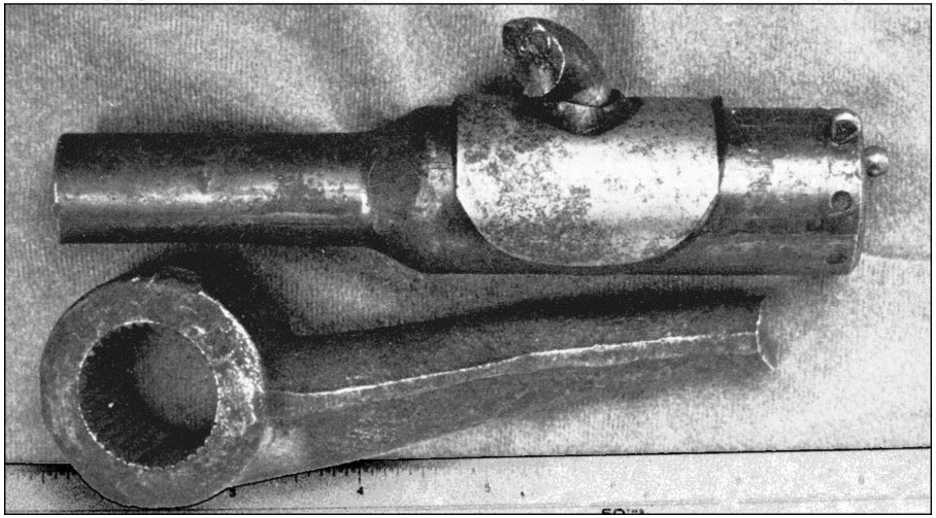


Fig. 6.4 Failure of an automotive drag link. The failure occured after about 225000 km. Fortunately the car was in park and against a curb.

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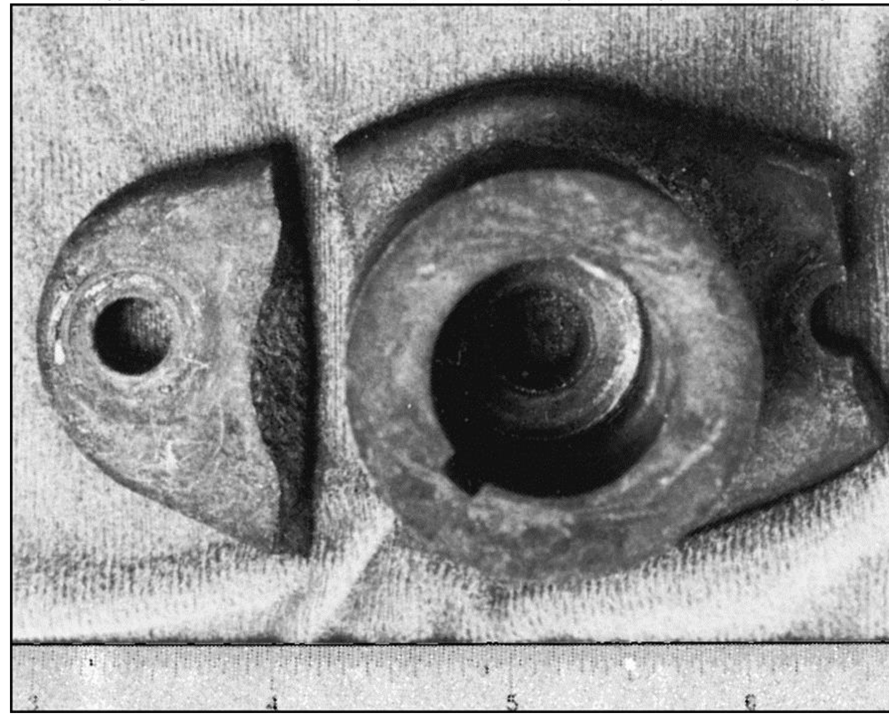

Fig. 6.5 Impact failure of a lawnmower blade driver hub. The blade impacted a surveying pipe marker.

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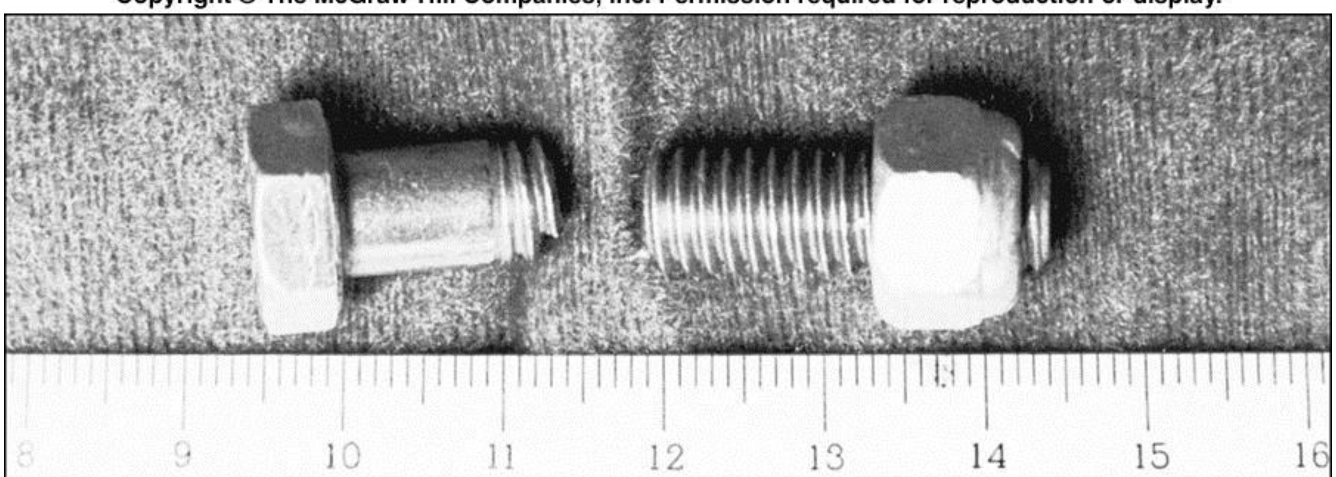

Fig. 6.6 Failure of an overhead-pulley retaining bolt on a weightlifting machine. A manufacturing error caused a gap that forced the bolt to take the entire moment load.

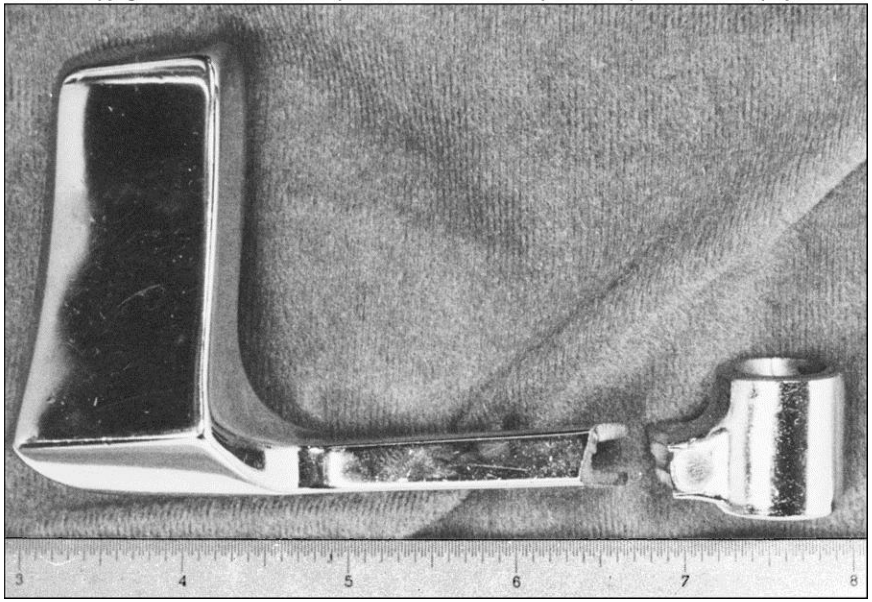

Fig. 6.7 Failure of an interior die-cast car-door handle. Failure occured about every 72000 km. Probable causes were the electroplating material, stress concentration, the long lever arm required to operate a “sticky” door-release mechanism, and the high actuation forces.

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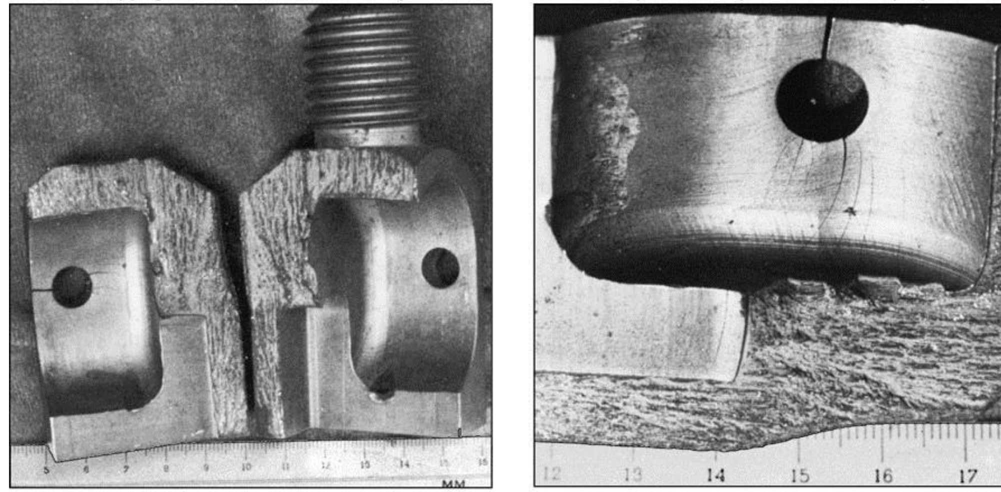

(*a*) (*b*)

Fig. 6.8 Chain test fixture that failed in one cycle. To alleviate complaints of excessive wear, the manufacturer decided to case-harden the material. (a) Two halves showing fracture; this is an excellent example of brittle fracture initiated by stress concentration. (b) Enlarged view of one portion to show cracks induced by stress concentration at the support-pin holes.

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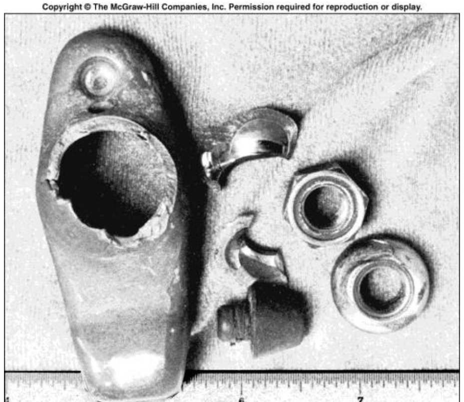

Fig. 6.9 Automotive rocker-arm articulation-joint fatigue failure

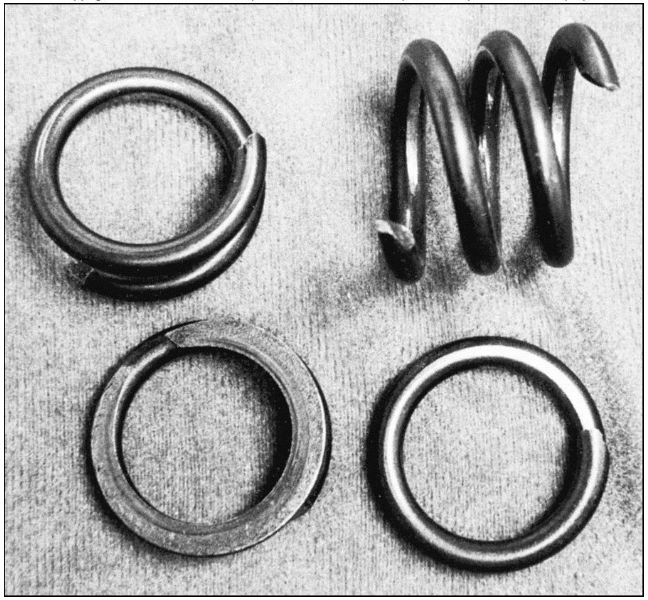

Fig. 6.10 Valve-spring failure caused by spring surge in an oversped engine. The fractures exhibit the classic 45º shear failure.

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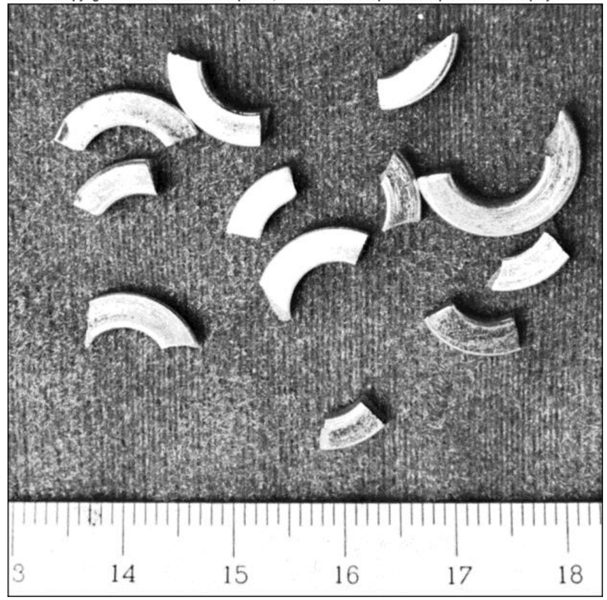

Fig. 6.11 Brittle fracture of a rock washer in one-half cycle. The washer failed when it was installed.

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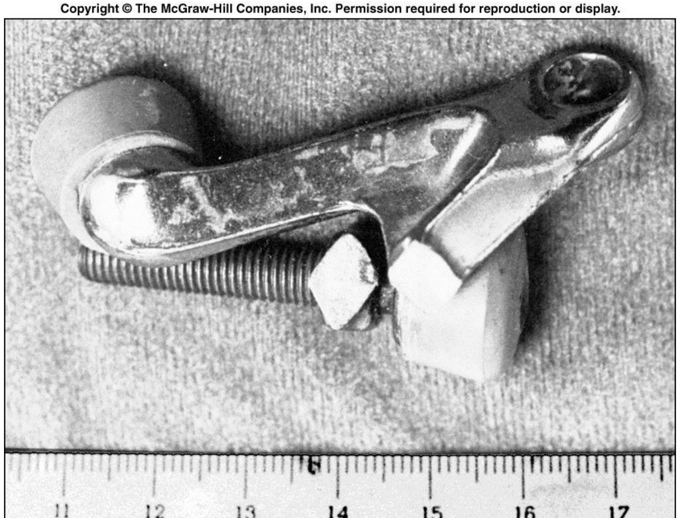

Fig. 6.12 Fatigue failure of a die-cast residence door bumper. This bumper is installed on the door hinge to prevent the doorknob from impacting the wall.

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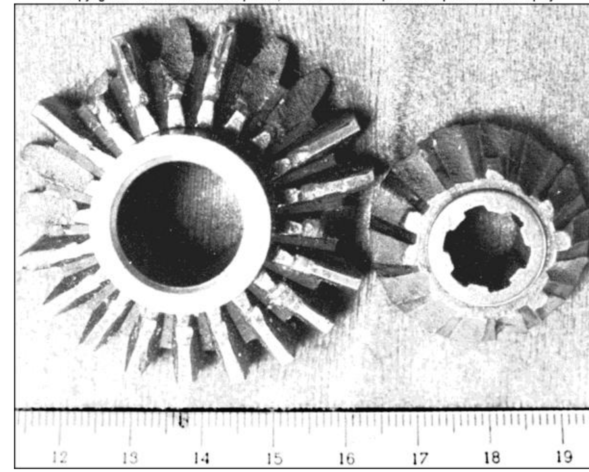


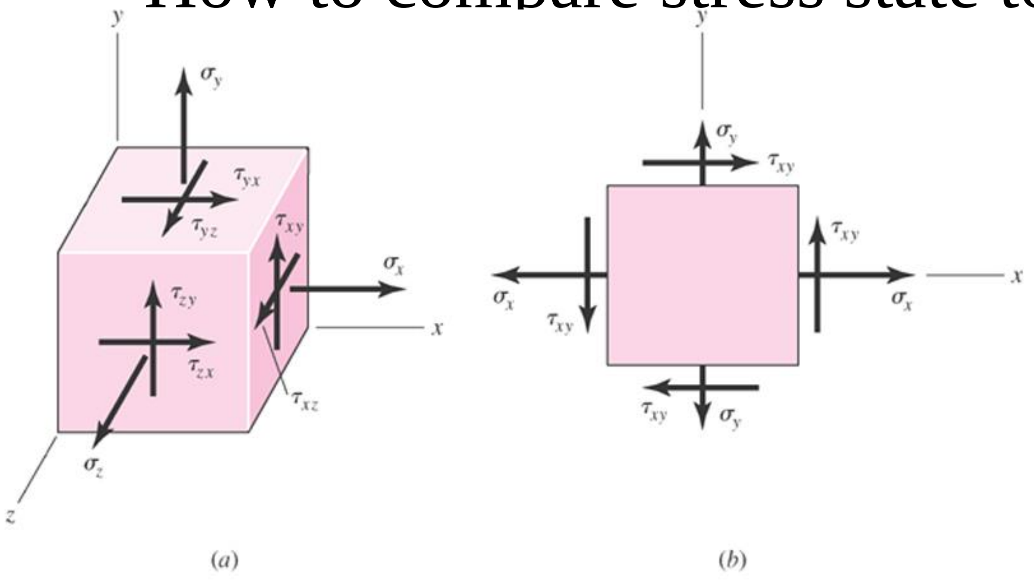
Fig. 6.13 A gear failure from a 5.6-kW American-made outboard motor. The large gear has a 47.6 mm outside diameter and had 21 teeth; 6 are broken. The pinion had 14 teeth; all are broken. Failure occured when the propeller struck a steel auger placed in the lake bottom as an anchorage. The owner had replaced the shear pin with a substitute pin.

Need for Static Failure Theories

- Uniaxial stress element (e.g. tension test)

$$n = \frac{Strength}{Stress} = \frac{S}{\sigma}$$

- Multi-axial stress element
  - One strength, multiple stresses
  - How to compare stress state to single strength?



Hypotheses of Failure : Ductile Materials

Maximum-Shear-Stress (Tresca or Guest) Hypothesis

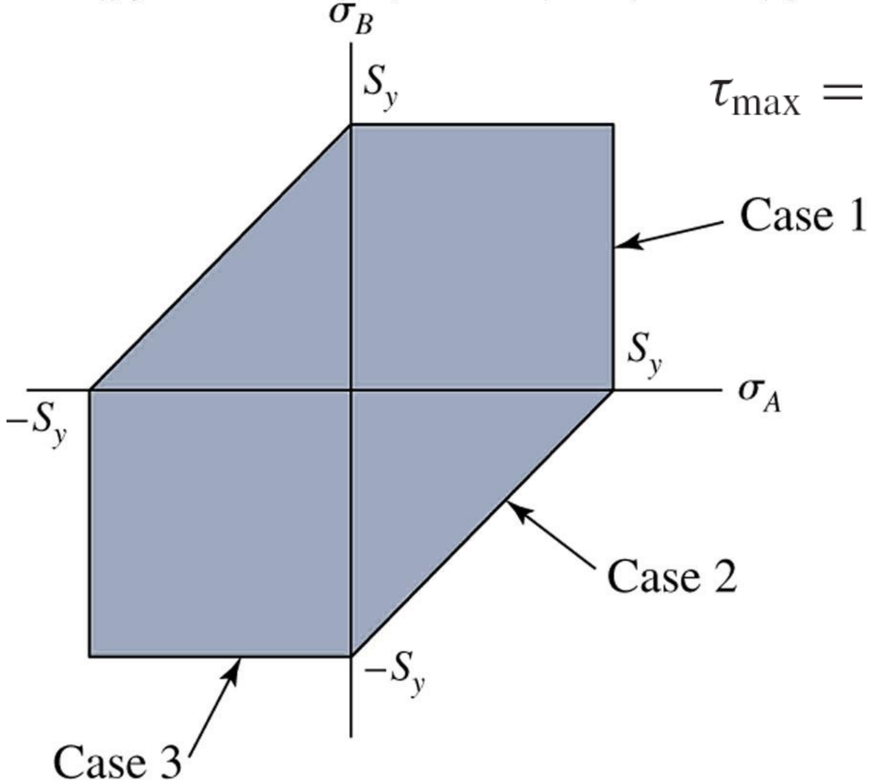


Fig. 6.15 The maximum-shear-stress (MSS) hypothesis for biaxial stresses.

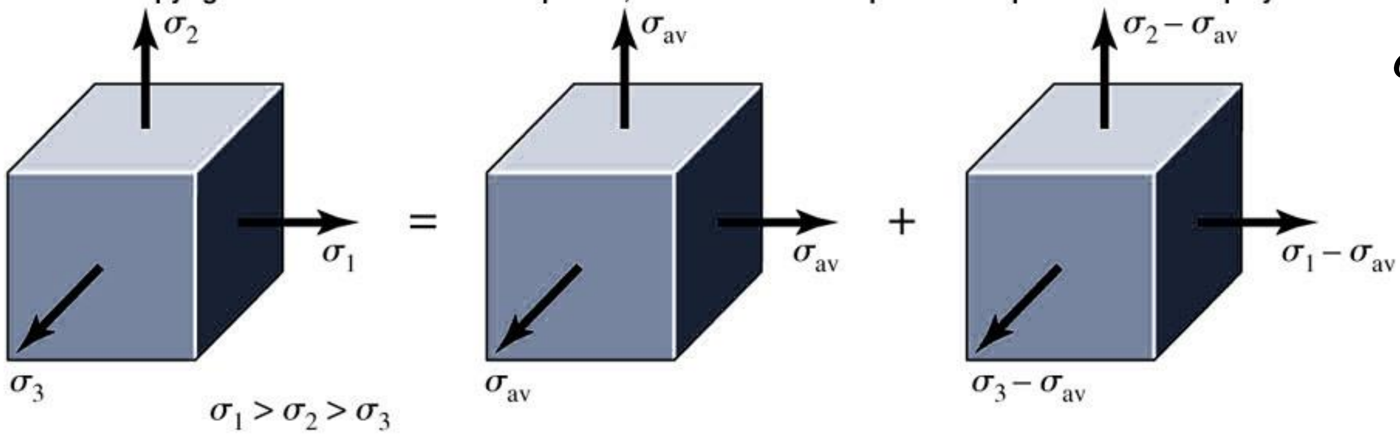
$$\tau_{\max} = \frac{\sigma_1 - \sigma_3}{2} \geq \frac{S_y}{2} \qquad \text{or} \qquad \sigma_1 - \sigma_3 \geq S_y$$

$$\sigma_A \geq S_y$$

$$\sigma_A - \sigma_B \geq S_y$$

$$\sigma_B \leq -S_y$$

Strain Energy Hypothesis



(*a*) Triaxial stresses (*b*) Hydrostatic component (*c*) Distortional component

$$\sigma_{av} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$$

Fig. 6.16 (a) Element with triaxial stresses; this element undergoes both volume change and angular distorsion. (b) Element under hydrostatic tension undergoes only volume change. (c) Element has angular distorsion without volume change.

$$u = \frac{1}{2E}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\nu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1\right]$$

$$u_v = \frac{1-2\nu}{6E}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + 2\sigma_1\sigma_2 + 2\sigma_2\sigma_3 + 2\sigma_3\sigma_1\right]$$

$$u_d = \frac{1+\nu}{3E}\left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}\right]$$

Distorsion Energy Hypothesis (von Mises, Shear Energy, or Octahedral Shear Stress Hypothesis)

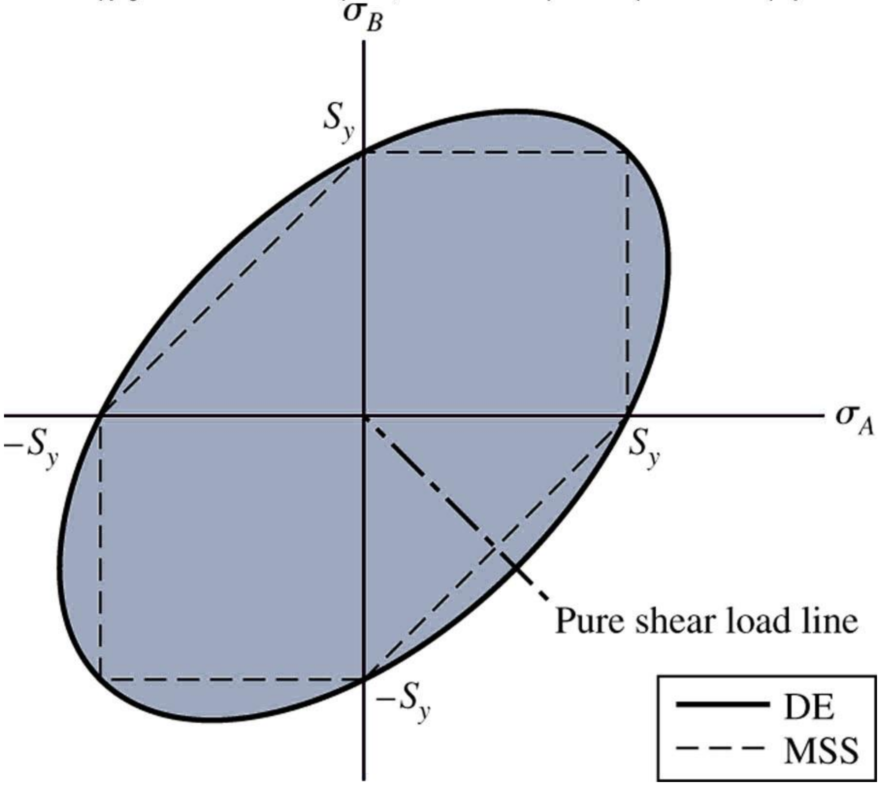


Fig. 6.17 The distorsion-energy (DE) theory for biaxial stress states.

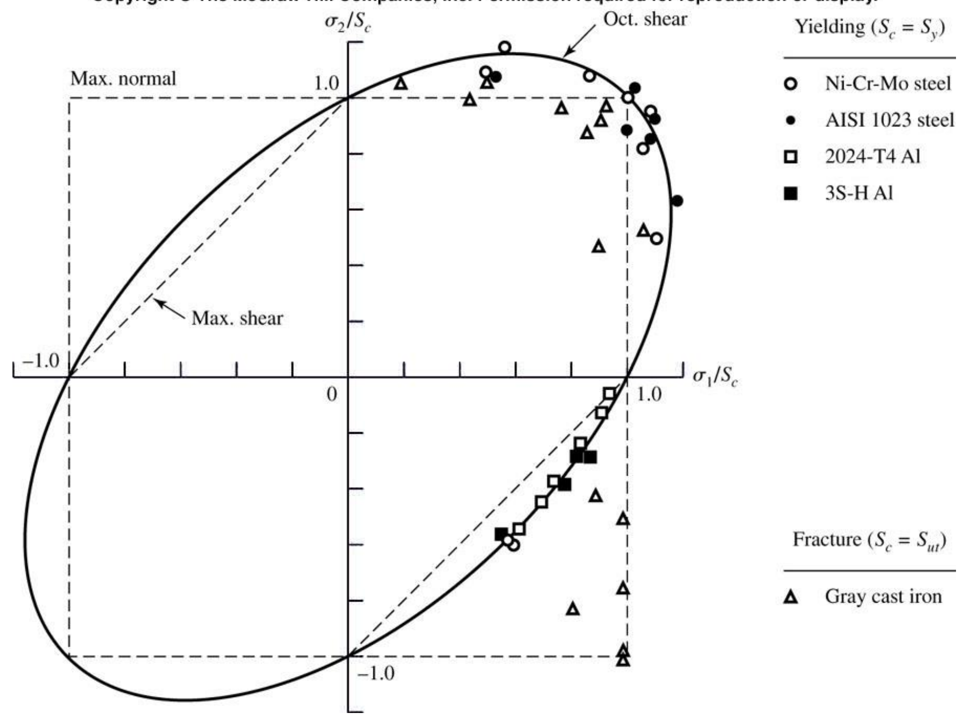


Fig. 6.23 Experimental data superposed on failure hypothesis.

$$\left[\frac{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6\left(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2\right)}{2}\right]^{1/2}\le S_y$$

Hypotheses of Failure : Brittle Materials

Maximum-Normal-Stress (Rankine) Hypothesis

Maximum-normal-stress hypothesis states that failure occurs whenever one of the three principal stresses equals or exceeds the strength.

$$\sigma_1 > \sigma_2 > \sigma_3 \qquad n\sigma_1 = S_t \quad \text{or} \quad n\sigma_3 = -S_c$$

Modifications of the Mohr Hypothesis

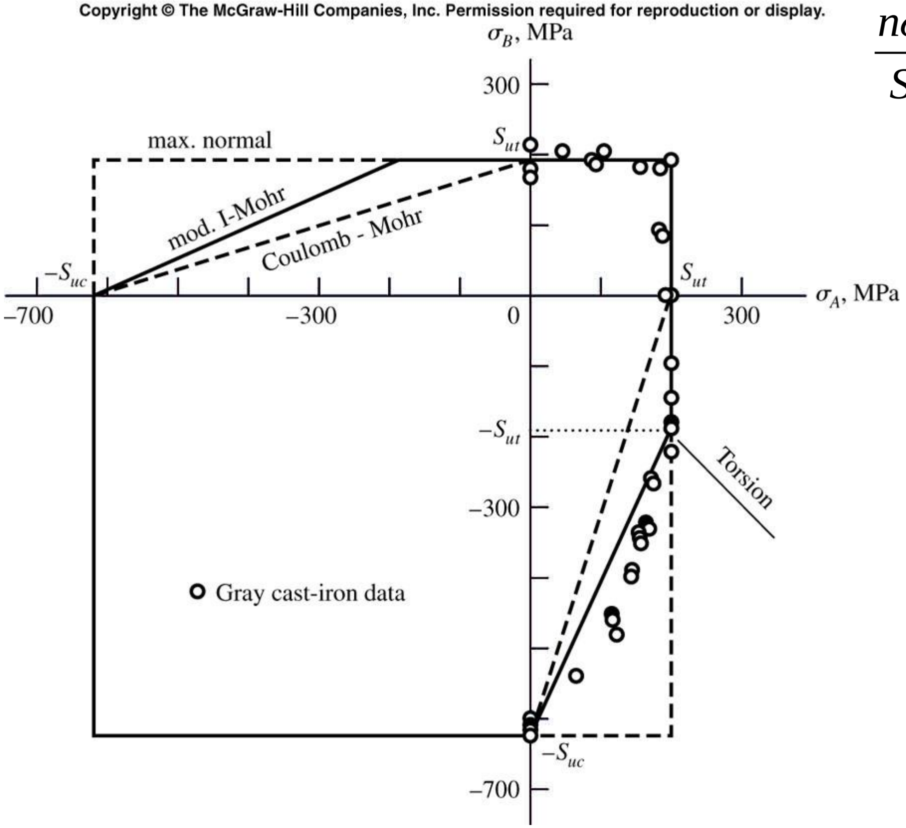


Fig. 6.27 Biaxial fracture data of gray cast iron compared with various failure data.

Mod. II-Mohr

$$\frac{n\sigma_A}{S_{ut}} = 1 - \left(\frac{n\sigma_B + S_{ut}}{-S_{uc} + S_{ut}}\right)^2 \qquad 0 \le \sigma_A \le S_{ut} \qquad -S_{uc} \le \sigma_B \le -S_{ut}$$

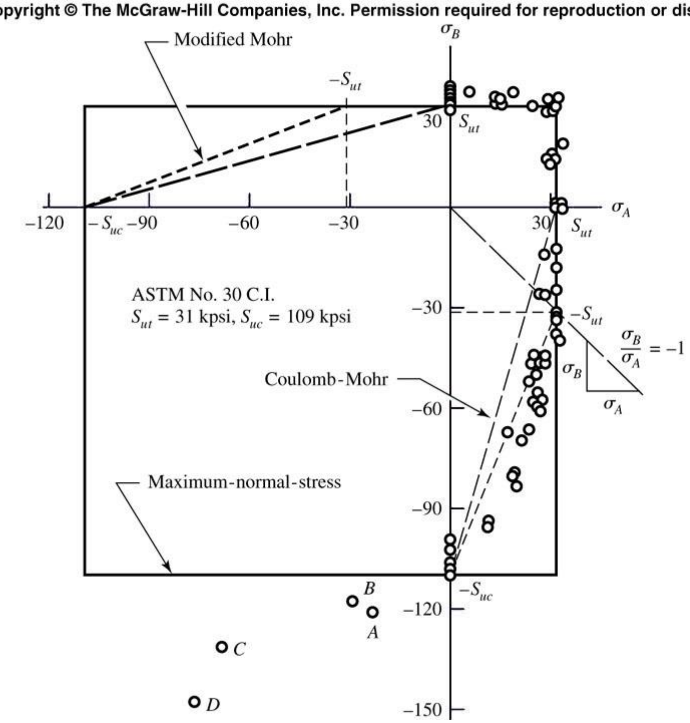


Fig. 6.29 Aplot of experimental data points obtained from tests on cast iron.

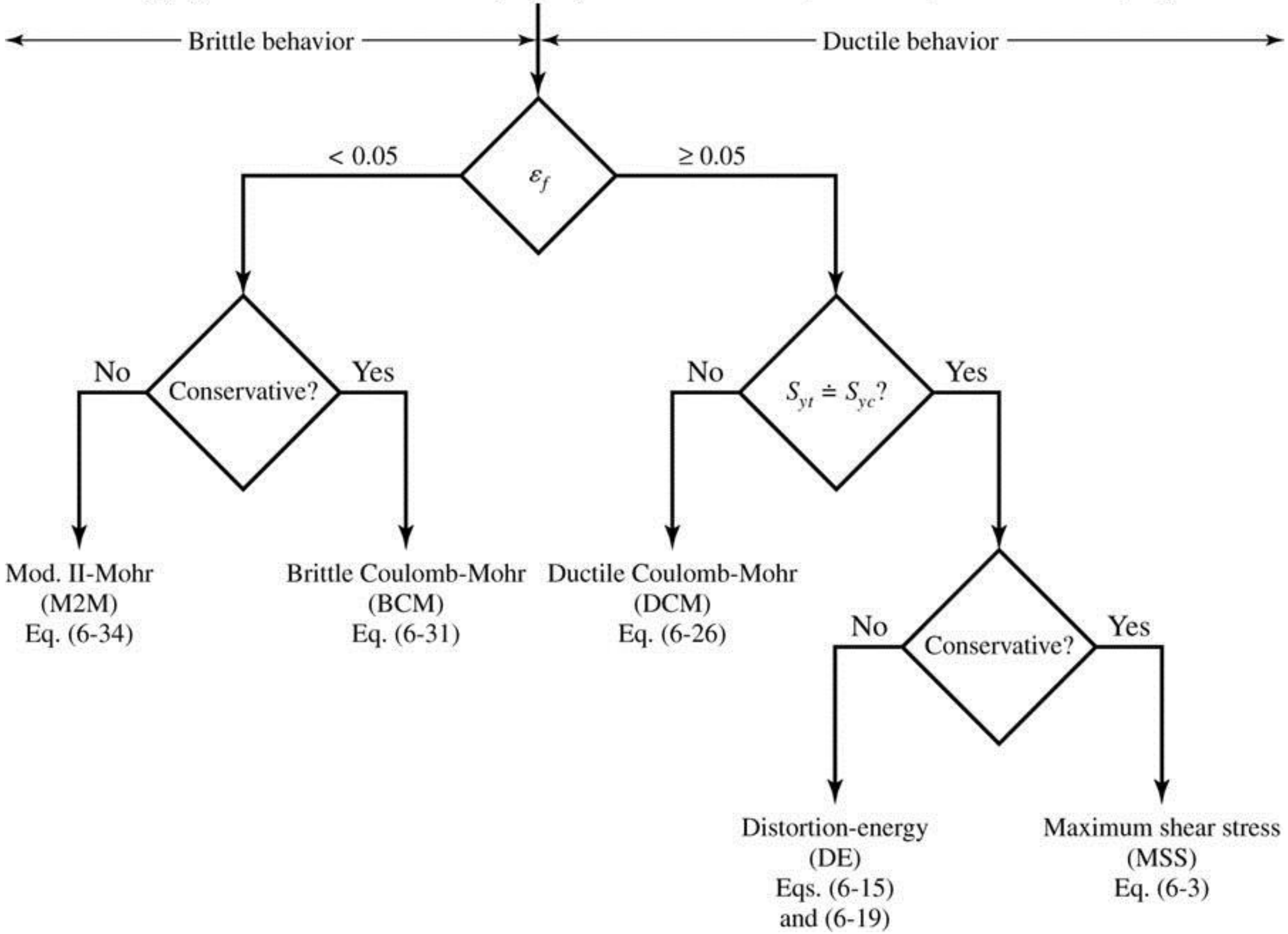


Fig. 6.30 Models describe data, and data criticize models.