Chapter 7, Problem 1
What are the characteristics of the surface of a brittle fracture of a metal?

Chapter 7, Solution 1
A brittle fracture surface typically appears shiny with flat facets which are created during cleavage fracture.

Chapter 7, Problem 2
Describe the three stages in the brittle fracture of a metal.

Chapter 7, Solution 2
The three stages of brittle fracture are:

1. As a result of plastic deformation, dislocations become concentrated along slip planes;
2. Shear stresses increase in areas where dislocations are impeded from movement. As a result, microcracks are nucleated.
3. Microcracks propagate as a result of further increases in shear stress. Stored elastic strain energy can also contribute to the propagation.

Chapter 7, Problem 3
Describe the three stages in the ductile fracture of a metal.

Chapter 7, Solution 3
The three stages consist of:

1. The specimen elongates, forming a necked region in which cavities form.
2. The cavities coalesce in the neck center, forming a crack which propagates toward the specimen surface in a direction perpendicular to the applied stress.
3. As the crack approaches the surface, its growth direction shifts to 45° with respect to the tension axis. This redirection allows for the formation of the cup-and-cone configuration and facilitates fracture.

Chapter 7, Problem 4
What are the characteristics of the surface of a ductile fracture of a metal?

Chapter 7, Solution 4
A ductile fracture surface has a dull, fibrous appearance and often resembles a "cup-and-cone" configuration.

Chapter 7, Problem 5
What does the fracture toughness mean?

Chapter 7, Solution 5
The critical value of the stress-intensity factor that causes failure of the plate is called the fracture toughness of the material.

Chapter 7, Problem 6

Why are ductile fractures less frequent in practice than brittle fractures?

Chapter 7, Solution 6

Ductile fracture is less frequent because it is accompanied with excessive plastic deformation. Plastic deformation could easily be picked up through inspection and the part could be changed before complete failure.

Chapter 7, Problem 7

Differentiate between transgranular and intergranular fractures.

Chapter 7, Solution 7

In the intergranular type of fracture, the crack propagates along the grain boundary due to embrittlement through segregation of impurities. On the contrary, transgranular fracture refers to a situation where the crack propagates through the matrix of the grain (most brittle fractures are of this form).

Chapter 7, Problem 8

What is the ductile to brittle transition temperature?

Chapter 7, Solution 8

From the result of impact testing of metals, the transition temperature from ductile to brittle behavior is called a ductile to brittle transition temperature.

Chapter 7, Problem 9

How does the carbon content of a plain-carbon steel affect the ductile-brittle transition temperature range?

Chapter 7, Solution 9

As the carbon content of the steel increases, the ductile-brittle transition temperature range increases in terms of both the width of the range and the temperature values.

Chapter 7, Problem 10

Describe the mechanism for the formation of slipband extrusions and intrusions.

Chapter 7, Solution 10

Plastic deformation in one direction and then in the reverse direction causes surface ridges and grooves called slipbands extrusions and slipband intrusions to be created on the surface of the metal specimen as well as damage within the metal along persistent slipbands.

Chapter 7, Problem 11

What two distinct types of surface areas are usually recognized on a fatigue failure surface?

Chapter 7, Solution 11

The two distinct types of surface areas typically observed on a fatigue failure surface are: a smooth region of "beach" marks created by rubbing action between the crack surface areas; and a rough region which is formed through the fracture process.

Chapter 7, Problem 12

Where do fatigue failures usually originate on a metal section?

Chapter 7, Solution 12

Fatigue failures typically originate at a point of high stress concentration, such as a sharp corner or notch.

Chapter 7, Problem 13

Describe the four major factors that affect the fatigue strength of a metal.

Chapter 7, Solution 13

The four primary factors which affect the fatigue strength of a metal are: stress concentration, surface roughness, surface condition and environment.

Chapter 7, Problem 14

Describe the four basic structural changes that take place when a homogeneous ductile metal is caused to fail by fatigue under cyclic stresses.

Chapter 7, Solution 14

For a homogeneous ductile metal subjected to fatigue, four stages of structural changes are observed:

1. *Crack initiation*: Plastic deformation causes the onset and early development of fatigue damage.
2. *Slipband crack growth (Stage I):* Slipband intrusions and extrusions are created on the surface of the metal while damage along persistent slipbands occurs within the sample. As a result, cracks form at or near the surface and propagate along planes subjected to high shear stresses.
3. *Crack growth on planes of high tensile stress (Stage II):* The slow crack growth of Stage I is replaced by rapid crack propagation as the crack direction shifts to a direction perpendicular to the direction of maximum tensile stress. During this stage, striations are formed.
4. *Ultimate ductile failure:* The crack achieves an area sufficient to cause the rupture of the sample by ductile fracture.

Chapter 7, Problem 15

What is a fatigue test *SN* curve, and how are the data for the *SN* curve obtained?

Chapter 7, Solution 15

A fatigue test *SN* curve is a plot of the fatigue stress to which a specimen is subjected versus the corresponding cycles, or stress reversals, up to and including the point of failure. The number of cycles is plotted on a logarithmic scale while the fatigue strength is plotted on either a linear or logarithmic scale, depending on the data. The *SN* data is typically obtained by repeatedly subjecting a rotating specimen to reverse or fluctuating bending while counting the cycles until destruction occurs. However, specimens may also be subjected to reversed or fluctuating axial stresses, torsional stresses, or combined stresses in testing.

Chapter 7, Problem 16

What is metal creep?

Chapter 7, Solution 16

Creep of a metal refers to the slow, progressive plastic deformation of a metal subjected to a constant load or stress. Thus creep is the time dependent strain of a metal.

Chapter 7, Problem 17

How does the *SN* curve of a carbon steel differ from that of a high-strength aluminum alloy?

Chapter 7, Solution 17

In an *SN* curve for a carbon steel, the stress at failure levels off as the number of cycles exceeds the metal's endurance limit of approximately 10^6 cycles. Whereas the *SN* curve for a high strength aluminum alloy continues to gradually decrease as the number of cycles is increased above 10^6.

Chapter 7, Problem 18

For which environmental conditions is the creep of metals especially important industrially?

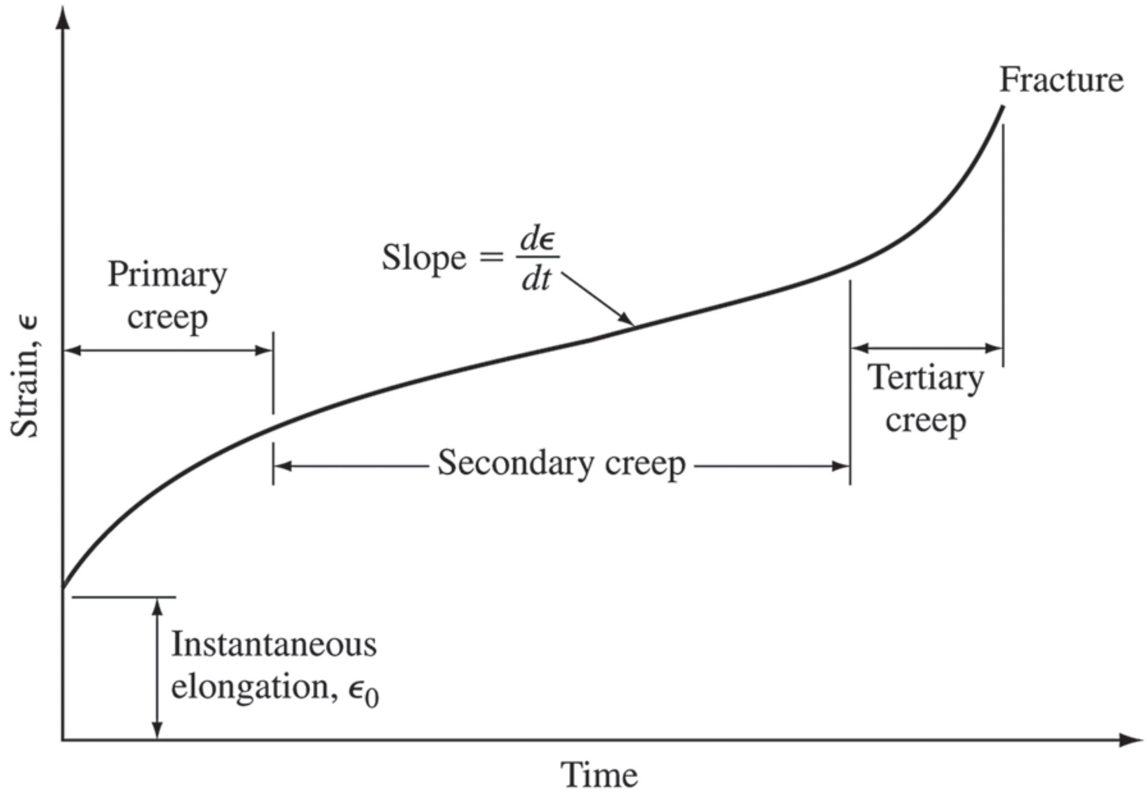
Chapter 7, Solution 18

Creep is of particular importance to industrial applications involving high stress and high temperature environments.

Chapter 7, Problem 19

Draw a typical creep curve for a metal under constant load and at a relatively high temperature, and indicate on it all three stages of creep.

Chapter 7, Solution 19



Chapter 7, Problem 20

Determine the critical crack length for a through crack contained within a thick plate of 7075-T751 aluminum alloy that is under uniaxial tension. For this alloy $K_{IC} = 24 \text{ MPa}\sqrt{\text{m}}$ and $\sigma_f = 560$ MPa. Assume $Y = \sqrt{\pi}$.

Chapter 7, Solution 20

$$K_{IC} = Y\sigma_f\sqrt{\pi a}$$

$$a = \frac{1}{\pi}\left[\frac{K_{IC}}{Y\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{24 \text{ MPa}\sqrt{\text{m}}}{\sqrt{\pi}(560 \text{ MPa})}\right]^2 = 0.000186 \text{ m} = 0.186 \text{ mm}$$

For an internal through crack, the critical length is $a_c = 2a =$ **0.381 mm**

Chapter 7, Problem 21

Determine the critical crack length for a through crack in a thick plate of 7150-T651 aluminum alloy that is in uniaxial tension. For this alloy $K_{IC} = 25.5 \text{ MPa}\sqrt{\text{m}}$ and $\sigma_f = 400$ MPa. Assume $Y = \sqrt{\pi}$.

Chapter 7, Solution 21

$$K_{IC} = Y\sigma_f\sqrt{\pi a}$$

$$a = \frac{1}{\pi}\left[\frac{K_{IC}}{Y\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{25.5\text{ MPa}\sqrt{\text{m}}}{\sqrt{\pi}(400.0\text{ MPa})}\right]^2 = 4.12\times10^{-4}\text{ m}$$

For an internal through crack, the critical length is $a_c = 2a = 8.24\times10^{-4}$ m = **0.824 mm.**

Chapter 7, Problem 22

The critical stress intensity (K_{IC}) for a material for a component of a design is $25\text{ MPa}\sqrt{\text{m}}$. What is the applied stress that will cause fracture if the component contains an internal crack 3.3 m long? Assume Y = 1.

Chapter 7, Solution 22

The applicable crack length is $a = \frac{1}{2}a_c$ = (3.3 m)/2 = 0.00165 mm. Substituting,

$$\sigma_f = \frac{K_{IC}}{Y\sqrt{\pi a}} = \frac{25\text{ MPa}\sqrt{\text{m}}}{(1)\sqrt{\pi(0.00165\text{ mm})}} = \mathbf{347.2\text{ MPa}}$$

Chapter 7, Problem 23

What is the largest size (mm) internal through crack that a thick plate of aluminum alloy 7075-T651 can support at an applied stress of (*a*) three-quarters of the yield strength and (*b*) one-half of the yield strength? Assume Y = 1.

Chapter 7, Solution 23

What is the largest size (mm) internal through crack that a thick plate of aluminum alloy 7075-T651 can support at an applied stress of (a) three-quarters of the yield strength and (b) one-half of the yield strength? Assume $Y = 1$.

From Table 7.1, for 7075-T651, $K_{IC} = 24.2\ \text{MPa}\sqrt{\text{m}}$ and $\sigma_{\text{YS}} = 495$ MPa.

(a) Given $\sigma_f = \frac{3}{4}\sigma_{YS}$, we calculate, $\sigma_f = \frac{3}{4}(495\ \text{MPa}) = 371.25\ \text{MPa}$. Assuming $Y = 1$, the crack length is,

$$a = \frac{1}{\pi}\left[\frac{K_{IC}}{Y\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{24.2\ \text{MPa}\sqrt{\text{m}}}{(1)(371.25\ \text{MPa})}\right]^2 = 1.35\times10^{-3}\ \text{m} = 1.35\ \text{mm}$$

Thus, for an internal through crack, $a_c = 2a =$ **2.70 mm**

(b) Given $\sigma_f = \frac{1}{2}\sigma_{YS} = \frac{1}{2}(495\ \text{MPa}) = 247.5\ \text{MPa}$, and assuming $Y = 1$,

$$a = \frac{1}{\pi}\left[\frac{K_{IC}}{Y\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{24.2\ \text{MPa}\sqrt{\text{m}}}{(1)(247.5\ \text{MPa})}\right]^2 = 3.04\times10^{-3}\ \text{m} = 3.04\ \text{mm}$$

Thus, for an internal through crack, $a_c = 2a =$ **6.08 mm**.

Chapter 7, Problem 24

Determine the critical crack length (mm) for a through crack in a thick 2024-T6 alloy plate that has a fracture toughness $K_{\text{IC}} = 25.1\ \text{MPa}\sqrt{\text{m}}$ and is under a stress of 250 MPa. Assume $Y = 1$.

Chapter 7, Solution 24

$$K_{IC} = Y\sigma_f\sqrt{\pi a}$$

$$a = \frac{1}{\pi}\left[\frac{K_{IC}}{Y\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{25.1\ \text{MPa}\sqrt{\text{m}}}{(1)(250.0\ \text{MPa})}\right]^2 = 3.20\times10^{-3}\ \text{m} = 3.20\ \text{mm}$$

For an internal through crack, the critical length is $a_c = 2a =$ **6.40 mm.**

Chapter 7, Problem 25

A Ti-6Al-4V alloy plate contains an internal through crack of 1.20 mm. What is the highest stress (MPa) that this material can withstand without catastrophic failure? Assume $Y = \sqrt{\pi}$.

Chapter 7, Solution 25

The applicable crack length is $a = ½\, a_c = (1.20 \text{ mm})/2 = 0.6$ mm. And from Table 7.1,

$K_{IC} = 55.0 \text{ MPa}\sqrt{\text{m}}$. Substituting,

$$\sigma_f = \frac{K_{IC}}{Y\sqrt{\pi a}} = \frac{55.0 \text{ MPa}\sqrt{\text{m}}}{\pi\sqrt{(6\times10^{-4}\text{m})}} = \mathbf{714.7\ MPa}$$

Chapter 7, Problem 26

Using the equation $K_{\text{IC}} = \sigma_f\sqrt{\pi a}$, plot the fracture stress (MPa) for aluminum alloy 7075-T651 versus surface crack size a (mm) for a values from 0.2 mm to 2.0 mm. What is the minimum size surface crack that will cause catastrophic failure?

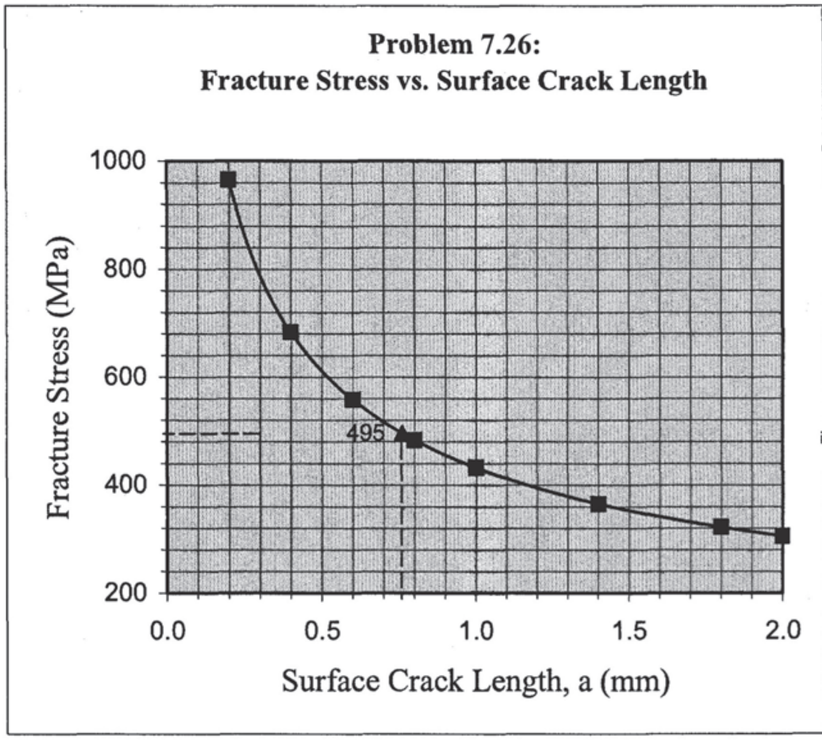
Chapter 7, Solution 26

In order to generate the required plot, we must first calculate the fracture stress for values of a ranging from 0.2 mm to 2.0 mm using the given relation:

$$\sigma_f = \frac{K_{IC}}{\sqrt{\pi a}}$$ where $K_{IC} = 24.2 \text{ MPa}\sqrt{\text{m}}$ based on Table 7.1. Substituting,

$$\sigma_f = \frac{24.2 \text{ MPa}\sqrt{\text{m}}}{\sqrt{\pi a}} = \frac{13.6534 \text{ MPa}\sqrt{\text{m}}}{\sqrt{a}}$$

This relation is used to calculate and plot the following values of fracture stress versus crack size.



Crack Length, a (mm)	Fracture Stress, σ_f (MPa)
0.2	965.4
0.4	682.7
0.6	557.4
0.8	482.7
1.0	431.8
1.4	364.9
1.8	321.8
2.0	305.3

The minimum surface crack length, for catastrophic failure, would correspond to a fracture stress equal to the material's yield stress value. Thus, from Table 7.1, $\sigma_{\text{YS}} = 495$ MPa. Substituting,

$$a = \frac{1}{\pi}\left[\frac{K_{IC}}{\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{24.2 \text{ MPa}\sqrt{\text{m}}}{495.0 \text{ MPa}}\right]^2 = 0.76\times10^{-3} \text{ m} = \mathbf{0.76\,mm}$$

This point has been included in the plot generated for fracture stress vs. surface crack size. One may deduce that for crack lengths above the minima of 0.76 mm, the alloy will fracture catastrophically. Whereas, for values of a less than 0.76 mm, the alloy will yield and fracture at 495 MPa in the normal manner.

Chapter 7, Problem 27

A fatigue test is made with a maximum stress of 172 MPa and a minimum stress of –27.6 MPa. Calculate (*a*) the stress range, (*b*) the stress amplitude, (*c*) the mean stress, and (*d*) the stress ratio.

Chapter 7, Solution 27

(a) The range of stress is $\sigma_r = \sigma_{\max} - \sigma_{\min}$ = 172 MPa – (–27.6 MPa) = 199.8 MPa

(b) The stress amplitude is $\sigma_a = \dfrac{\sigma_r}{2} = 99.9$ **MPa**.

(c) The mean stress is $\sigma_m = \dfrac{\sigma_{\max} + \sigma_{\min}}{2} = \dfrac{172 \text{ MPa} - 27.6 \text{ MPa}}{2} = 72.3$ **MPa**.

(d) The stress ratio is $R = \dfrac{\sigma_{\min}}{\sigma_{\max}} = \dfrac{-27.6 \text{ MPa}}{172 \text{ MPa}} = -0.16.$

Chapter 7, Problem 28

A fatigue test is made with a mean stress of 120 MPa and a stress amplitude of 165 MPa. Calculate (*a*) the maximum and minimum stresses, (*b*) the stress ratio, and (*c*) the stress range.

Chapter 7, Solution 28

Given $\sigma_m =$ 120 MPa and $\sigma_a = 165$ MPa,

(a)
$$2\sigma_m = 2(120 \text{ MPa}) = \sigma_{\max} + \sigma_{\min}$$
$$240 \text{ MPa} = \sigma_{\max} + \sigma_{\min}$$
$$2\sigma_a = 2(165 \text{ MPa}) = \sigma_{\max} - \sigma_{\min}$$
$$330 \text{ MPa} = \sigma_{\max} - \sigma_{\min}$$

Adding these two equations and solving,

$$\sigma_{\max} = \mathbf{285.9\ MPa}, \quad \sigma_{\min} = \mathbf{-44.8\ MPa}$$

(b)
$$R = \frac{\sigma_{\min}}{\sigma_{\max}} = \frac{-44.8 \text{ MPa}}{285.9 \text{ MPa}} = \mathbf{-0.157}$$

(c)
$$\sigma_r = \sigma_{\max} - \sigma_{\min} = 285.9 \text{ MPa} - (-44.8 \text{ MPa}) = \mathbf{330.7\ MPa}$$

Chapter 7, Problem 29

A large flat plate is subjected to constant-amplitude uniaxial cyclic tensile and compressive stresses of 120 and 35 MPa, respectively. If before testing the largest surface crack is 1.00 mm and the plain-strain fracture toughness of the plate is $35\ \text{MPa}\sqrt{\text{m}}$, estimate the fatigue life of the plate in cycles to failure. For the plate, $m = 3.5$ and $A = 5.0 \times 10^{-12}$ in MPa and meter units. Assume $Y = 1.3$.

Chapter 7, Solution 29

The final crack length, from the fracture toughness equation, is:

$$a_f = \frac{1}{\pi}\left[\frac{K_{IC}}{Y\sigma_f}\right]^2 = \frac{1}{\pi}\left[\frac{35\ \text{MPa}\sqrt{\text{m}}}{(1.3)(120\ \text{MPa})}\right]^2 = 0.01602\ \text{m} = 16.02\ \text{mm}$$

The fatigue life in cycles, N_f, is then,

$$N_f = \frac{a_f^{-(m/2)+1} - a_0^{-(m/2)+1}}{[-(m/2)+1]A\sigma^m \pi^{m/2} Y^m} = \frac{(0.0160\ \text{m})^{-1.75+1} - (0.001\ \text{m})^{-1.75+1}}{[-1.75+1](5.0\times10^{-12})(120\ \text{MPa})^{3.5}\pi^{1.75}(1.3)^{3.5}}$$

$$= \mathbf{1.18\times10^5\ cycles}$$

Chapter 7, Problem 30

Refer to Prob. 7.29: If the initial and critical crack lengths are 1.25 and 12 mm, respectively, in the plate and the fatigue life is 2.0×10^6 cycles, calculate the maximum tensile stress in MPa that will produce this life. Assume $m = 3.0$ and $A = 6.0 \times 10^{-13}$ in MPa and m units. Assume $Y = 1.20$.

Chapter 7, Solution 30

The maximum tensile stress is calculated as:

$$\sigma_m = \frac{a_f^{-(m/2)+1} - a_0^{-(m/2)+1}}{[-(m/2)+1]A\pi^{m/2}Y^m N_f}$$

$$\sigma^3 = \frac{(0.012\ \text{m})^{-\frac{3}{2}+1} - (0.00125\ \text{m})^{-\frac{3}{2}+1}}{\left[-\frac{3}{2}+1\right](6.0\times10^{-13})(\pi^{1.5})(1.2)^3(2.0\times10^6)} = 3.318\times10^6$$

$$\sigma = \mathbf{149\ MPa}$$

Chapter 7, Problem 31

Refer to Prob. 7.29: Compute the final critical surface crack length if the fatigue life must be a minimum of 7.0×10^5 cycles. Assume the initial maximum edge surface crack length of 1.80 mm and a maximum tensile stress of 160 MPa. Assume $m = 1.8$ and $A = 7.5 \times 10^{-13}$ in MPa and meter units. Assume $Y = 1.25$.

Chapter 7, Solution 31

The final critical crack length can be using the equation for fatigue life,

$$N_f = \frac{a_f^{-(m/2)+1} - a_0^{-(m/2)+1}}{\left[-(m/2)+1\right] A\sigma^m \pi^{m/2} Y^m}$$

$$7\times10^5 = \frac{a_f^{-\frac{1.8}{2}+1} - (0.0018\text{ m})^{-\frac{1.8}{2}+1}}{\left[-(1.8/2)+1\right](7.5\times10^{-13})(160\text{ MPa})^{1.8}\pi^{1.8/2}(1.25)^{1.8}}$$

$$7\times10^5 = \frac{a_f^{0.1} - 0.5315}{2.913\times10^{-9}}$$

$$0.5336 = a_f^{0.1}$$

$$a_f = \mathbf{0.00187\text{ m} = 1.87\text{ mm}}$$

Chapter 7, Problem 32

Refer to Prob. 7.29: Compute the critical surface edge crack if the fatigue life must be 8.0×10^6 cycles and maximum tensile stress is 144.7 MPa. m =1.8 and A=7.5×10^{-13} in MPa and meter units. Initial crack (edge) is 3.05 mm Y=1.25.

Chapter 7, Solution 32

$$N_f = \frac{a_f^{-(m/2)+1} - a_0^{-(m/2)+1}}{\left[-(m/2)+1\right] A\sigma^m \pi^{m/2} Y^m}$$

$$8\times10^6 = \frac{a_f^{-\frac{1.8}{2}+1} - (0.00305\text{ m})^{-\frac{1.8}{2}+1}}{\left[-(1.8/2)+1\right](7.5\times10^{-13})(144.7\text{ MPa})^{1.8}\pi^{1.8/2}(1.25)^{1.8}}$$

$$8\times10^6 = \frac{a_f^{-0.1} - 0.5603}{2.4309\times10^{-9}}$$

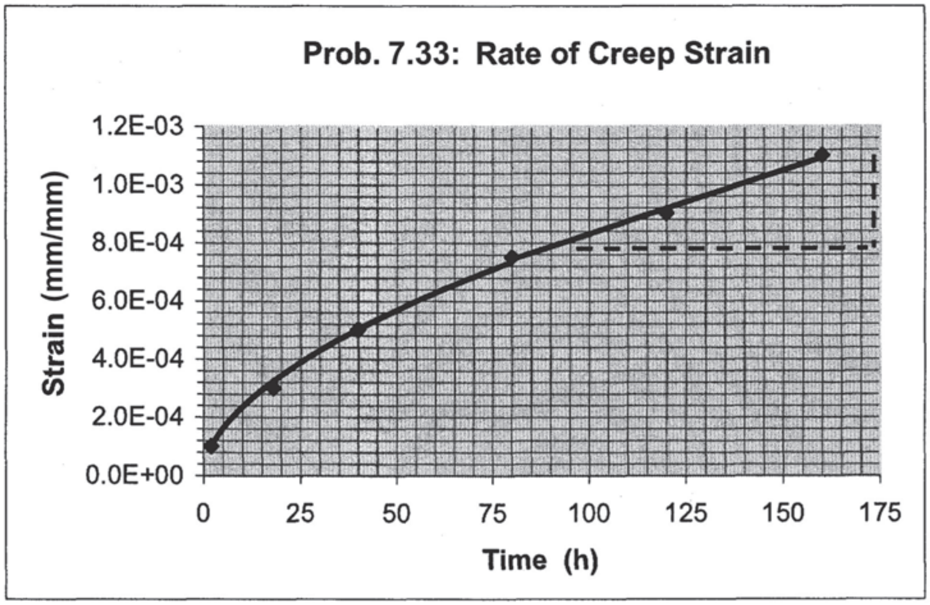
$$a_f = (0.5797)^{1/0.1} = 4.2893\times10^{-3}\text{m} = \mathbf{4.28\text{ mm}}$$

Chapter 7, Problem 33

The following creep data were obtained for a titanium alloy at 345 MPa and 400°C. Plot the creep strain versus time (hours), and determine the steady-state creep rate for these test conditions.

Strain (mm/mm)	Time (h)	Strain (mm/mm)	Time (h)
0.010×10^{-2}	2	0.075×10^{-2}	80
0.030×10^{-2}	18	0.090×10^{-2}	120
0.050×10^{-2}	40	0.11×10^{-2}	160

Chapter 7, Solution 33



$$\text{Creep Rate} = \frac{\Delta\varepsilon}{\Delta t} = \frac{(1.1\times10^{-3})-(0.76\times10^{-3})}{160\text{ h}-85\text{ h}} = 4.53\times10^{-6}\text{ mm/mm/h}$$

Chapter 7, Problem 34

If DS CM 247 LC alloy (middle graph of Fig. 7.31) is subjected to a temperature of 960°C for 3 years, what is the maximum stress that it can support without rupturing?

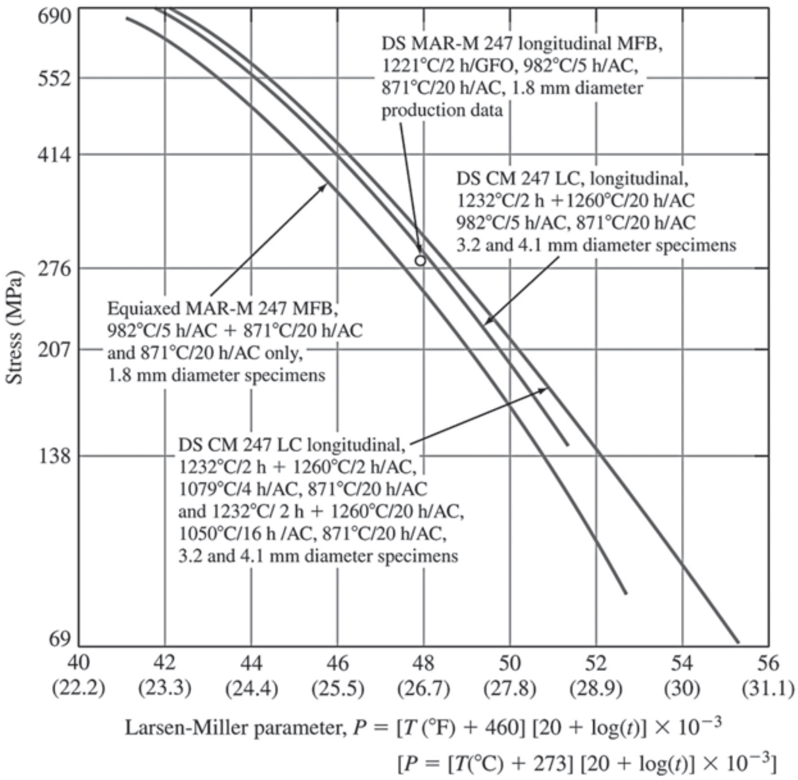


Figure 7.31

Chapter 7, Solution 34

Given $t_r = 3 \text{ yr} = 26{,}280 \text{ h}$ and $T = 960^\circ\text{C} + 273 = 1233 \text{ K}$,

$$P = 1233(\log 26{,}280 + 20) = 30{,}109$$

From Fig. 7.31, for $P = 30.1 \times 10^3$, the stress is approximately **96 MPa**.

Chapter 7, Problem 35

Equiaxed MAR-M 247 alloy is to support a stress of 276 MPa (Fig. 7.31). Determine the time to stress rupture at 850°C.

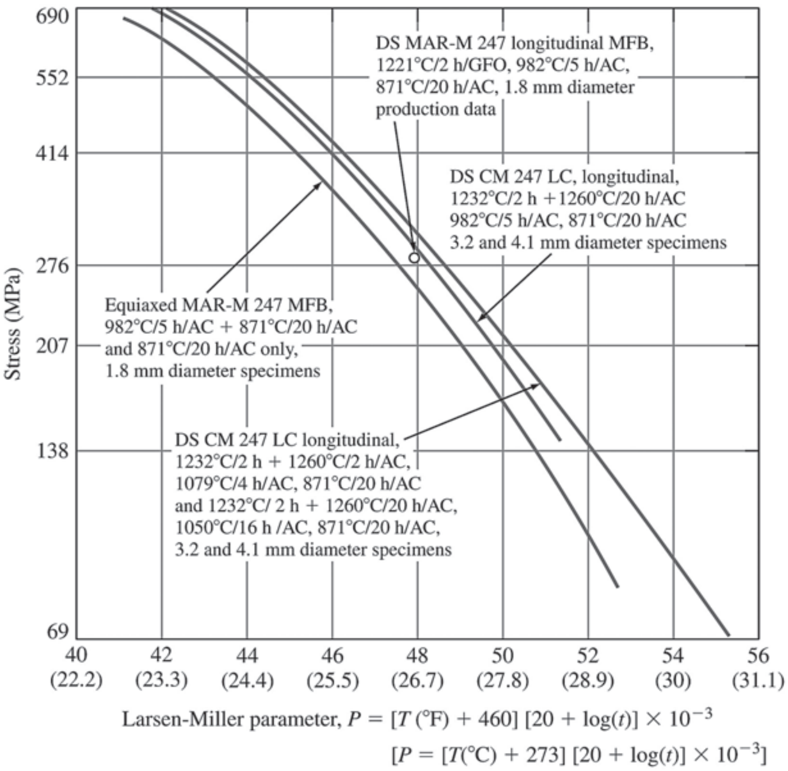


Figure 7.31

Chapter 7, Solution 35

From Fig. 7.31, for a stress of 276 MPa, the L.M. parameter value for Equiaxed MAR-M 247 is 26×10^3 K·h. Thus,

$$P = T(K)(20+\log t_r), \quad T = 850^\circ\mathrm{C} + 273 = 1123\ \mathrm{K}$$

$$26{,}000 = (1123\ \mathrm{K})(20+\log t_r)$$

$$\log t_r = 3.152$$

$$t_r = \mathbf{1419\ h}$$

Chapter 7, Problem 36

DS MAR-M 247 alloy (Fig. 7.31) is used to support a stress of 414 MPa. At what temperature (°C), will the stress rupture lifetime be 210 h?

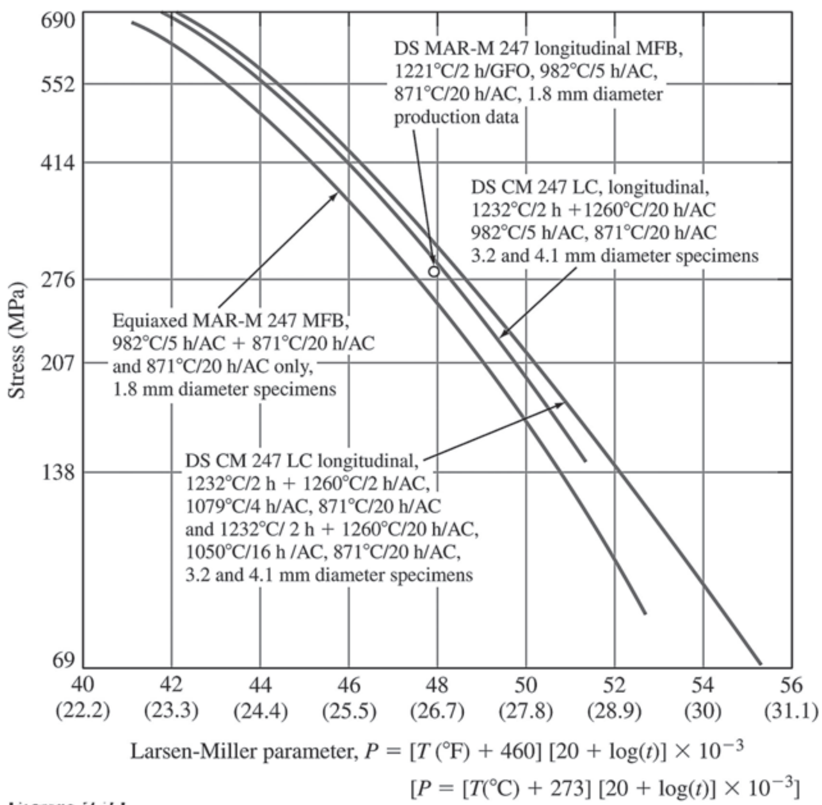


Figure 7.31

Chapter 7, Solution 36

From Fig. 7.31, for a stress of 414 MPa, the L.M. parameter value for DS MAR-M 247 alloy is 25.5×10^3 K·h. Thus,

$$P = T(K)(20 + \log t_r)$$

$$25{,}500 = [\mathrm{T(K)}](20 + \log\ (210\ \mathrm{h}))$$

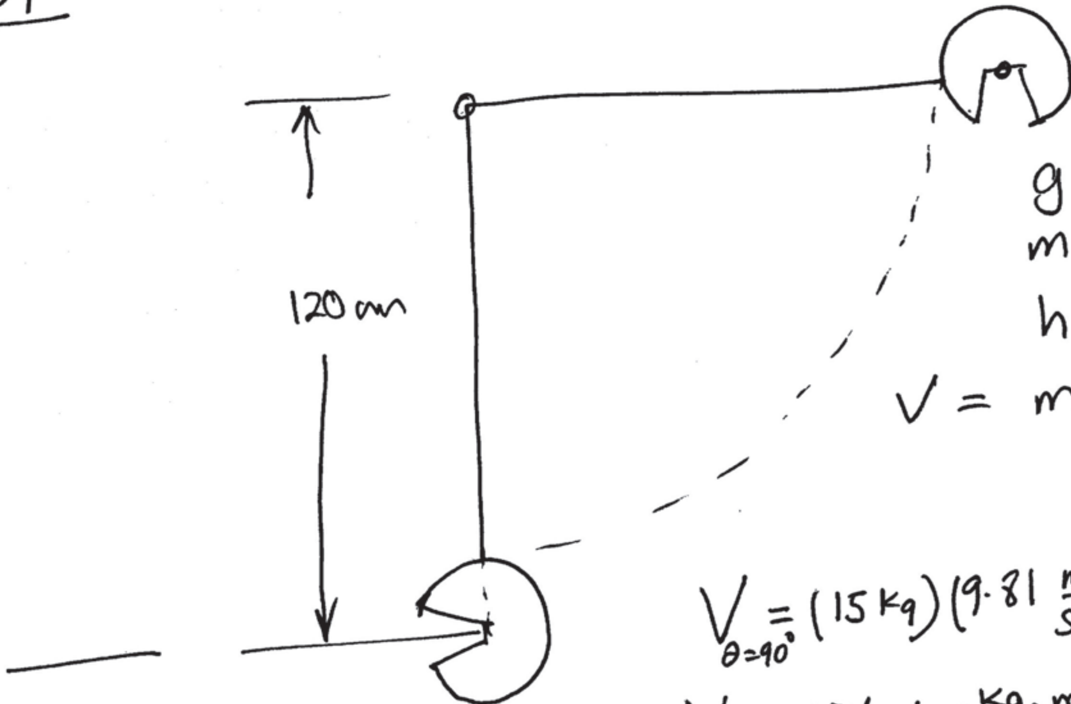
$$\mathrm{T(K)} = \frac{25{,}500}{22.32} = \mathbf{1142K = 869°C}$$

Chapter 7, Problem 39

A Charpy V-notch specimen is tested by the impact-testing machine in Fig. 7.9. In the test, the 15 kg hammer of arm-length 120 cm (measured from the fulcrum to the point of impact) is raised to 90° and then released. (*a*) What is the potential energy stored in the mass at this point? (*b*) After fracture of the specimen, the hammer swings to 45°. What is the potential energy at this point? (*c*) How much energy was expended in the fracture of the specimen? Hint: potential energy = mass × g × height.

7.39

a)



$g = 9.81 \frac{m}{s^2}$

$m = 15\ kg$

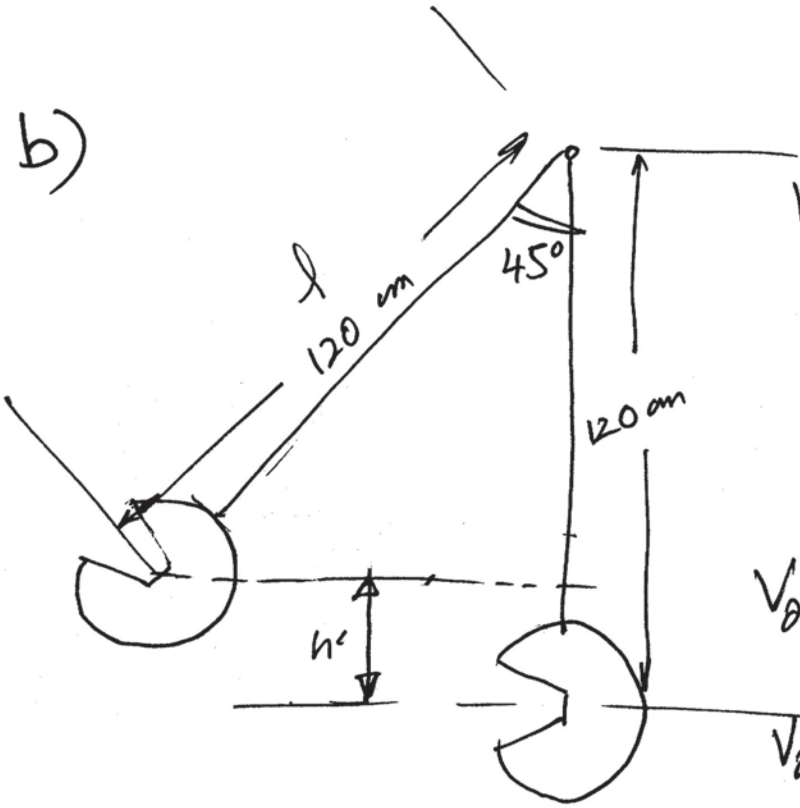
$h = 120\ cm$

$V = mgh$

$V_{\theta=90^\circ} = (15\ kg)(9.81\ \frac{m}{s^2})(1.2\ m)$

$V_{\theta=90^\circ} = 176.6 \underbrace{\left(\frac{kg \cdot m}{s^2}\right)}_{N} \cdot m = J$

b)



After Impact $\theta = 45°$

$$V_{\theta=45} = mgh'$$

$$h' = h - l\cos 45 = 120(1 - \cos 45°)$$

$$h' = +56.9 \text{ cm}$$

$$V_{\theta=45} = (15 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)(0.57 \text{ m})$$

$$V_{\theta=45} = 83.9 \text{ J}$$

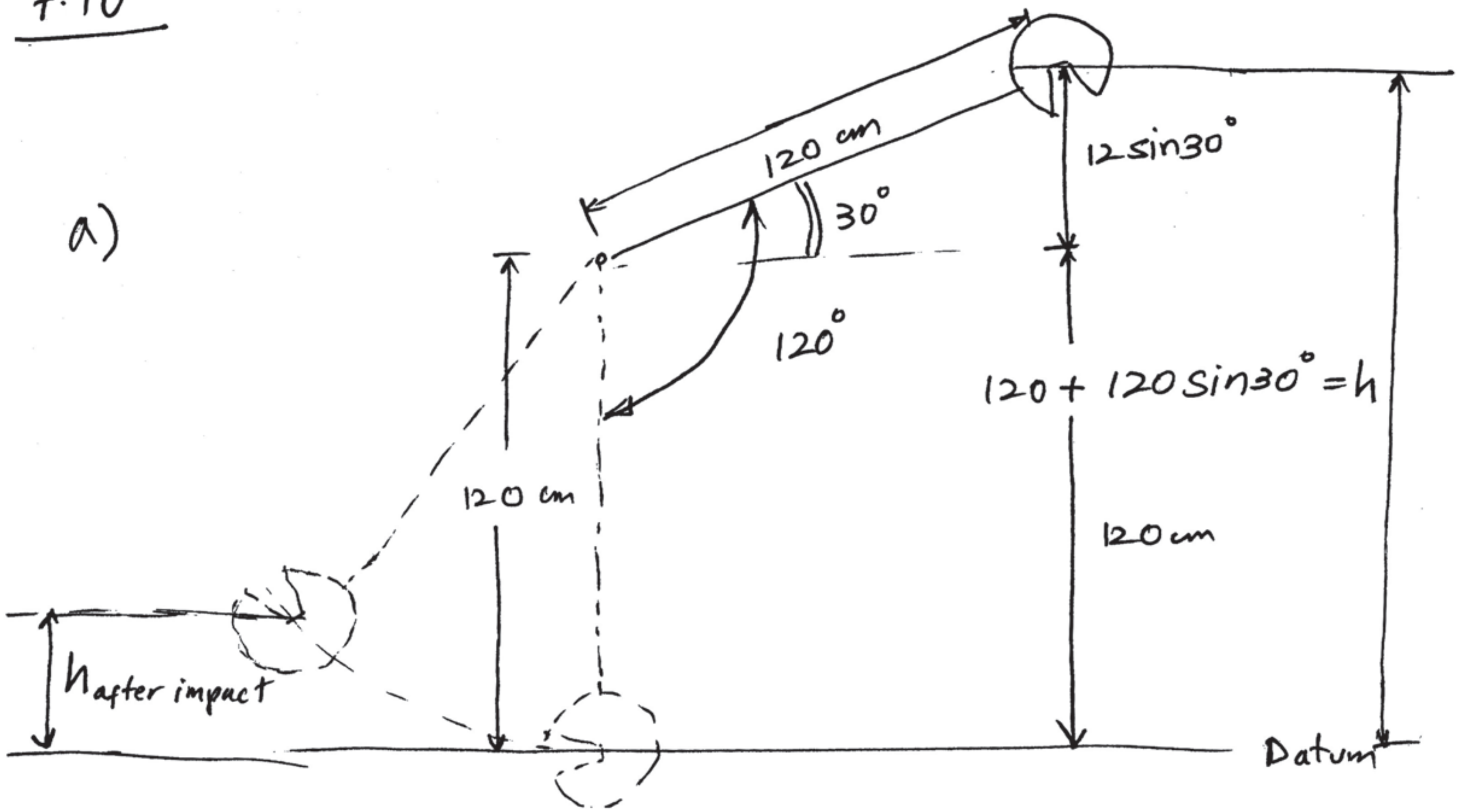
Energy lost during impact $= 176.6 - 83.9 = 92.7$ J
(toughness of the specimen)

Chapter 7, Problem 40

Assuming that the maximum angle the pendulum in problem 39 can rise to is 120° and if the V-notch specimen requires 220 J of energy for fracture, will the above system have sufficient capacity to achieve the fracture of the specimen? How much will the pendulum rise if it achieves fracture of the specimen?

7.40

a)



$$V = mgh = (15\text{ kg})(9.81)\left(\frac{120+60}{100}\right)$$

$$V = (15\text{ kg})(9.81\ \tfrac{m}{s^2})(1.8\ m) = 264.8\ J$$

b) The potential energy of 264.8 J is greater than 220 J required for fracture. Specimen will break.

c) $\Delta V = 264.8 - 220 = 44.8\ J$

$$\cancel{24}4.8 = mgh = (15\ kg)(9.81)(h)$$

$$\Rightarrow h = \frac{44.8\ J}{(15\ kg)(9.81\ \frac{m}{s^2})} = 0.3\ m = 30\ cm.$$

Chapter 7, Problem 41*

The circumferential stress, σ, (also called hoop stress) in a pressurized cylindrical vessel is calculated by the equation σ=Pr/t, where P is the internal pressure, r is radius of the vessel, and t its thickness. For a vessel of 91.44-cm diameter, 6.35-mm thickness and an internal pressure of 34.5 MPa, what would be the critical crack length if the vessel were made of (a) Al 7178-T651, (b) alloy steel (17-7pH)?
What is your conclusion? Use Table 7.1 for properties. (Use Y=1.0 and assume center crack geometry.)

7.41

$$\sigma = \frac{Pr}{t} = \frac{(34.5\ \text{MPa})(0.9144/2\ \text{m})}{0.00635\ \text{m}} = 2484\ \text{MPa}$$

(note a pressure of about 34.5 MPa crates a large hoop stress)

(a) If made of Al:

$K_{IC} = Y\sigma_f\sqrt{\pi a}$ $\qquad$ $K_{IC} = 23.06\ \text{MPa}\sqrt{m}$ for Al 7078 T651

$$23.06\ \text{MPa}\sqrt{m} = (1.0)(2484\ \text{MPa})\sqrt{\pi a}$$

$$\Rightarrow \sqrt{\pi a} = 0.00928 \qquad \Rightarrow a = 0.0000274\ m = 0.027\ mm$$

$$\text{Crack Length} = 2a = 0.054\ mm$$

(b) If made of 17-7 PH alloy steel:

$K_{IC} = Y\sigma_f\sqrt{\pi a}$ $\qquad$ $K_{IC} = 76.86 MPa$

$$76.86 MPa\sqrt{m} = (1.0)(2484 MPa)\sqrt{\pi a}$$

$$\Rightarrow \sqrt{\pi a} = 0.0309 \quad \Rightarrow \quad a = 0.000305 m = 0.305 mm$$

$$\text{crack length} = 2a = 0.61 mm$$

Conclusion: Using 17-7PH alloy steel will allow us to tolerate significantly larger cracks.

Chapter 7, Problem 42

For the vessel in problem 7.41, consider that it is made of Titanium alloy (Ti-6Al-4V). (*a*) If cracks of length a = 0.127 mm are detected in the vessel, what should the safe operating pressure be? What if cracks of length a = 5.08 mm are detected, what should the safe operating pressure be? Use Y 1.0 and assume center crack

7.42

$$K_{IC} = 54.9 \text{ MPa}\sqrt{m}$$

(a) $a = 0.127\text{mm} = 0.000127\text{m}$ (a is half crack length)

$$K_{IC} = Y\sigma_f\sqrt{\pi a} \Rightarrow 54.9 \text{ MPa}\sqrt{m} = (1.0)\,\sigma\sqrt{\pi(0.000127)}$$

$$\Rightarrow \sigma = \frac{54.9 \text{ MPa}\sqrt{m}}{\sqrt{\pi(0.000127)m}} = 2748.5 \text{ MPa}$$

$$\sigma = \frac{Pr}{t} \Rightarrow P = \frac{\sigma t}{r} = \frac{(2748.5)(0.00635)}{0.4572}$$

$$\Rightarrow P = 38.18 \text{ MPa} \text{ (maximum operating pressure)}$$

(b) $a = 5.08\text{mm} = 0.00508\text{m}$ (a is half crack length)

$$\sigma = \frac{54.9}{\sqrt{\pi(0.00508)}} = 434.6 \text{ MPa}$$

$$\Rightarrow P = \frac{\sigma t}{r} = \frac{(434.6)(0.00635)}{(0.4572)} = 6.1 \text{ MPa}$$

Note maximum operating pressure drops significantly with increase in crack length.

Chapter 7, Problem 43*

An ultrasonic crack detection equipment used by Company A can find cracks of length a = 5.08 mm and longer. A lightweight component is to be designed and manufactured and then inspected for cracks using the above machine. The maximum uniaxial stress applied to the component will be 413 MPa. Your choices of metals for the component are Al 7178 T651, Ti-6Al-4V, or 4340 steel as listed in Table 7.1. (*a*) Which metal would you select to make the component from? (*b*) Which metal would you choose when considering both safety and weight? (Use Y= 1.0 and assume center crack geometry.)

7.43

Cracks of $a = 5.08$ mm can be detected (half crack length)

$\sigma = 413$ MPa

Al 7178 T651 $\quad K_{IC} = 23.06$ MPa

Ti-6Al-4V $\quad K_{IC} = 54.90$ MPa

4340 steel $\quad K_{IC} = 60.39$ MPa

a) Al: $\quad 23.06 = (1.0)(413)\sqrt{\pi a} \Rightarrow a = 0.99$ mm

Ti: $\quad 54.90 = (1.0)(413)\sqrt{\pi a} \Rightarrow a = 5.63$ mm

Steel: $\quad 60.39 = (1.0)(413)\sqrt{\pi a} \Rightarrow a = 6.81$ mm

The critical crack length for aluminum is much smaller than what the machine can detect. Reject the alumium alloy as a choice.

The critical crack length for both Ti & Steel alloys are larger the length that the machine can detect. Either alloy will be acceptable but steel is safer.

b) Considering both safety and weight, Ti alloy is the best choice since it has a lower density.

Chapter 7, Problem 44

In problem 7.43, if you did not consider the existence of cracks at all and only considered yielding under uniaxial stress as a failure criterion, (*a*) which metal would you select to avoid yielding? (*b*) Which metal would you select to avoid yielding and have the lightest component? (Use data in Table 7.1)? Is it a safe design practice to assume that no initial cracks exist? Explain.

7.44

$\sigma = 414$ MPa

Al 7178 T651	$\sigma_y = 573$ MPa
Ti-6Al-4V	$\sigma_y = 1035$ MPa
4340 steel	$\sigma_y = 1518$ MPa

a) The applied uniaxial stress is lower than the yield strength of all metals. Thus, any of the three metals would work.

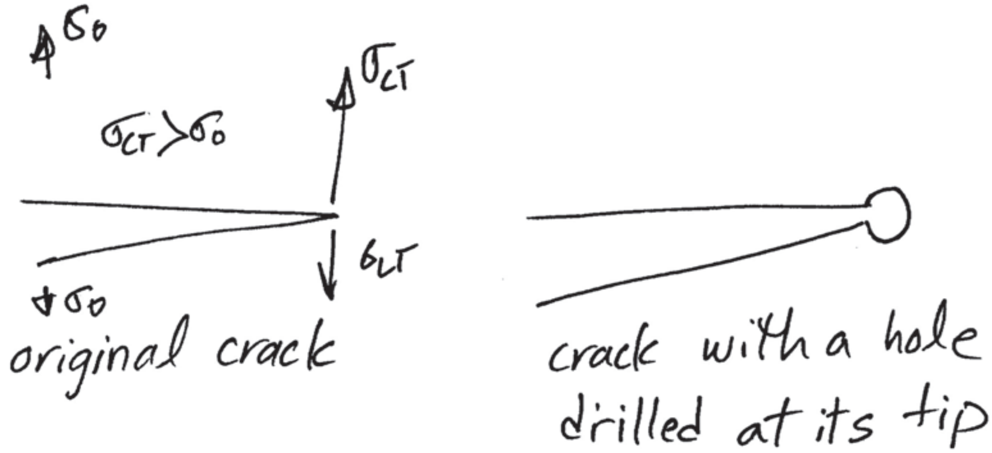
b) Al alloy would be a good alloy since its yield strength is considerably higher tha the applied stress but has a lower density than steel.

c) In problem 7.43, we should that the aluminum alloy will not be a good choice if you consider pre-existing cracks. Thus it is not a safe practice to assume that no cracks exist in the material. It will always be safer to assume cracks of certain length exist.

Chapter 7, Problem 45

It is a common practice in inspection of bridges (and other structures) that if a crack is found in the steel, the engineers will drill a small hole just ahead of the crack tip. How will this help?

7.45



The tip of the crack is very sharp. The stresses at the sharp tip become amplified to levels many times larger than the far-field stress. This will cause the crack to propagate.

If a hole is drilled at the crack tip, this will reduce the sharpness of the tip and will lower the state of stress. The existing crack will not propagate.

It is important to note that cracks of certain length (below critical length) are tolerable with appropriate factor of safety.

Chapter 7, Problem 46

An alloy steel plate is subjected to a tensile stress of 120 MPa. The fracture toughness of the materials is given to be 45 MPa $\sqrt{\text{m}}$. (*a*) Determine the critical crack length to assure the plate will not fail under the static loading conditions (assume Y = 1). (*b*) Consider the same plate under the action of cyclic tensile/compressive stresses of 120 MPa and 30 MPa respectively. Under the cyclic conditions, a crack length reaching 50% of the critical crack length under static conditions (part a) would be considered unacceptable. If the component is to remain safe for 3 million cycles, what is largest allowable initial crack length?

7.46

a)

$$45\times10^{6}\ \text{Pa}\cdot\text{m}^{1/2} = (1)(120\times10^{6}\ \text{MPa})\sqrt{\pi a}$$

$$\Rightarrow a = .035\ \text{m} = 3.5\ \text{cm}$$

a must be less than 0.035 for component to be safe at the given stress level.

b) (follow example 7.2)

a_f = Final crack length = 0.5 (0.035) = 0.018 m

$$N_f = \frac{a_f^{-(m/2)+1} - a_0^{-(m/2)+1}}{[-(m/2)+1]A\sigma^m \pi^{m/2} Y^m} \qquad m \neq 2$$

$a_f = 0.018\ m \qquad a_0 = ? \qquad N_f = 3\times10^{6}$ cycles

assume $A = 2.0\times10^{-12} \qquad m = 3 \qquad Y = 1$

$\sigma_r = 120 - 0$ (compressive stresses are ignored)

$$3\times10^{6} = \frac{0.018^{-(3/2)+1} - a_0^{-(3/2)+1}}{[-(3/2)+1](2.0\times10^{-12})\pi^{3/2}(120)^3(1)^3}$$

$$a_0^{-0.5} = -(3\times10^{6})(-0.5)(2.0\times10^{-12})\pi^{3/2}(120\times10^{6})^3(1)^3 + 0.018^{-0.5}$$

$\frac{1}{\sqrt{a_0}} = 2010 \Rightarrow a_0 = 2.4\times10^{-7}\ m$ or 2.4×10^{-4} cm

If initial cracks are longer than 2.4×10^{-4} cm, the component will have a life shorter than 3×10^{6} cycles.

Chapter 7, Problem 47

A cylindrical rod made of directionally solidified alloy CM 247 is to carry a 10,000 N load at a temperature of 900° C and for a period of 300 hours. Using the Larson-Miller plot in Fig. 7.31, design the appropriate dimensions for the cross section.

7.47 Larsen-Miller Parameter

$$P = T(K)(20 + \log t_r)$$

$$T\,°K = 900°C + 273 = 1173\,°K$$

$$t_r = 300 \text{ hrs}$$

$$P = 1173\,(20 + \log 300) = 26365$$

$$P \times 10^{-3} = 26.3$$

Refer to Figure 7.31, upper must graph

Enter with $P \times 10^{-3}$ of 26.3 (top axis)

and find the corresponding σ.

$$\sigma \sim 350 \text{ MPa}$$

$$F = 10{,}000 \text{ N} \qquad \sigma = 350 \text{ MPa}$$

$$\sigma = \frac{F}{A} \qquad A = \frac{F}{\sigma} = \frac{10{,}000 \text{ N}}{350 \times 10^6 \text{ Pa}} = 2.8 \times 10^{-5} \text{ m}^2$$

$$A = 0.28 \text{ cm}^2$$

$$A = \pi r^2 \Rightarrow r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{.28}{\pi}}$$

$$r = 0.30 \text{ cm}$$

Chapter 7, Problem 48

In the manufacturing of connecting rods, 4340 alloy steel heat treatable to 1790 MPa may be used. There are two options for the manufacturing of the component, (*i*) heat treat the component and use, and (*ii*) heat treat and ground the surface. Which option would you use and why?

7.48

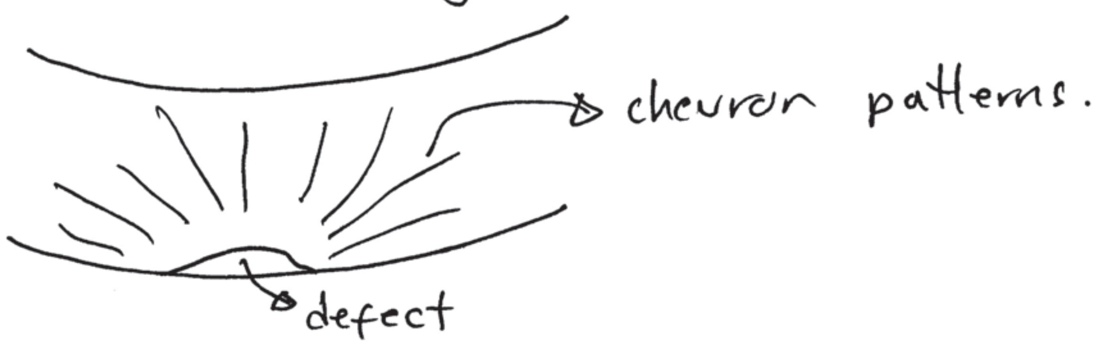
The component must have an excellent fatigue life. All factors to improve fatigue life must be considered. If the surface is improved through grinding process (smooth surface), the fatigue life will improve.

Chapter 7, Problem 49

Examine the fracture surface of a fractured steel tube. How would you classify this fracture? Can you tell where the fracture started from? How?

7.49

This fracture is a brittle fracture formed due to existence of a defect at the bottom of the tube. The chevron patterns radiating from the defect are signature of brittle type fractures. These patterns point to the origin of fracture.



The defect could be an inclusion, porosity, tiny cracks, etc...

Chapter 7, Problem 50

If you had a choice between an aluminum alloy, stainless steel, a plain low carbon steel alloy, and a plain high carbon steel alloy (all of which offer appropriate strength for the application) for a structural application in the Arctic regions which would you choose? Why? (Cost is not an issue.)

7.50

The material selected should have a Ductile-to-Brittle (DBT) Transition temperature that is significantly lower than the operating temp.

Notwithstanding factors such as heat treatment and processing, the composition and structure are important considerations. (strength is not an issue)

FCC metals do not undergo DBT. Thus aluminum alloys are good candidates. (Figure 7.10)

High carbon content will increase DBT and this is dangerous. (Figure 7.11)

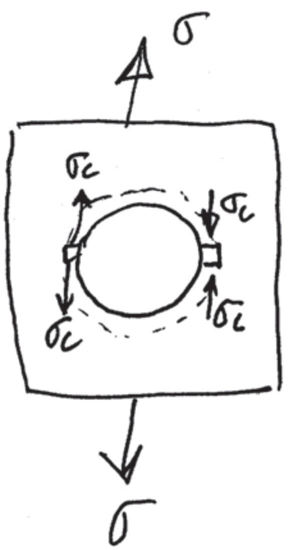
stainless steel, due to its low carbon content, will also be a good choice.

Chapter 7, Problem 51

In aircraft applications, aluminum panels are riveted together through holes drilled in the sheets. It is the industry practice to plastically expand the holes to the desired diameter at room temperature (this introduces compressive stresses on the circumference of the hole). (*a*) Explain why this process is done and how it benefits the structure. (*b*) Design a system that would accomplish the cold expansion process effectively and cheaply. (*c*) What are some precautions that must be taken during the cold expansion process?

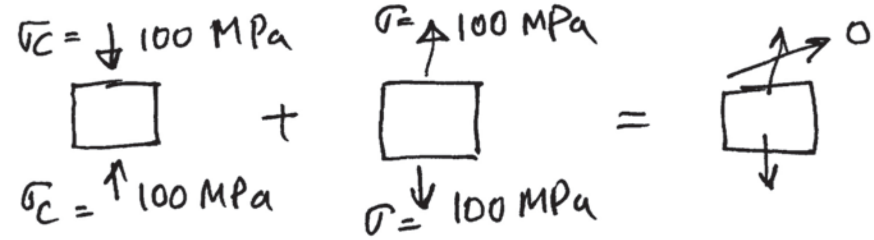
7.51

a) Introducing compressive residual stresses around a hole will improve its fatigue performance by reducing stress.



expanded hole

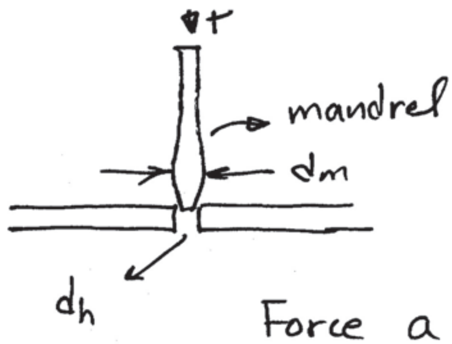
- assume a compressive stress of 100 MPa around the hole



- Add to it the externally applied stress of 100 MPa in tension. (ignore stress concentration effect)

- The point around the hole will be stress free.

If there is no initial compressive stress, the stress around the hole will be 100 MPa tensile.

b) 

$d_m = d_{mandrel}$

$d_h = d_{hole}$

$d_m > d_h$

Force a mandrel of diameter dm through the hole of diameter dh.

Since dm > dh, the hole will expand.

c) Care must be taken not to overdo the cold expansion. This could cause micro cracks that would be detrimental.

Chapter 7, Problem 52

What factors would you consider in selecting materials for coins? Suggest materials for this application.

7.52

- The metals should have the capacity to be formed with intricate patterns at room temperature. (coining process)
- The metals should have reasonable strength and durability.
- The metals should resist corrosion.
- The amount of metal used in the coin should be less in value than the value of the coin itself.

Penny: 3% copper, 97% Zinc
Nickel: 75% copper, 25% Nickel
Dime: 91% Copper, 9% Nickel
Quarter: 91% copper, 9% Nickel
Dollar (coin): 88% copper, 6% Manganese, 3% Zinc, and 3% Nickel.

Chapter 7, Problem 53

Examine the fracture surfaces below and discuss the differences in surface features. Can you identify the type and nature of the fracture?

7.53

Figure P7.53 a shows equiaxed dimpled surface similar to that in Figure 7.3. This is generally indicative of ductile fracture.

Figure P7.53b shows brittle cleavage fracture in which grain fracture along specific slip planes. (Similar to Figure 7.7) The fracture is transgranular.

Figure P7.53c shows intergranular brittle fracture. Note that the grains are clearly distinguishable and plastic deformation is not observed.

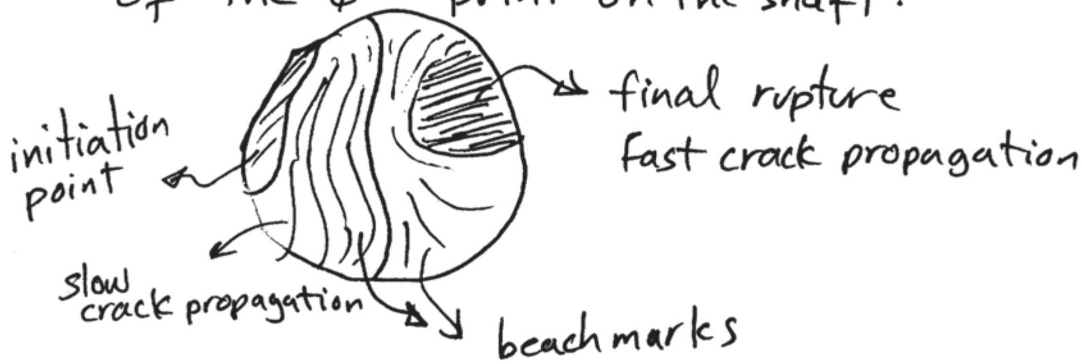
Chapter 7, Problem 54

The components in Fig. P7.54 is high strength steel racecar transmission shaft, which is cyclically loaded in torsion and some bending. The one at the bottom of Fig. P7.54*a* is fractured. Figure P7.54*b* shows a higher magnification image of the fracture path around the shaft. Figure P7.54*c* shows that cross-section of the fractured shaft. Based on this visual evidence speculate as much as possible about what happened to this shaft and where did the fracture start from. Especially, list your observations of Fig. P7.54*c*

7.54

Examination of Figure P7.54b shows that the shaft was indented to place the date of manufacturing on it. If you look closely, you will notice that the crack runs through the "Ø" print.

Examination of Figure P7.54C shows the initiation point on the left side of the shaft. This region corresponds to the location of the "Ø" print on the shaft.



The beach marks are clearly observed indicating step-wise crack propagation.

Once the crack propagates to a significant fraction of the area, the remaining intact section fractures catastrophically (final rupture).

Thus the cause of fracture was the indentation of the shaft "ϕ" which slowly grew into a large crack due to cyclic torsion and bending.