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NOTE TO THE INSTRUCTOR -- 6e SOLUTIONS MANUAL

At the beginning of each chapter of the solutions manual, the instructor will find "solutions" for the "b" problems. After the "b" problem solutions in each chapter, the solutions to the other problems in the chapter are presented.

The "b" problems are more basic problems written to "encourage" the student to read the textbook. The basic problems are generally short answer, some requiring definitions, although some are involved in helping to analyze and understand patents.

The problems and solutions not designated with a "b" are generally analytical in nature. If a "D" appears in the problem number the problem usually involves design and requires problem solver (student) decision-making.

The solutions manual serves both the needs of the print and electronic formats for the 6th edition.

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SOLUTIONS MANUAL
to accompany

FUNDAMENTALS OF MACHINE COMPONENT DESIGN

Sixth Edition

Chapter 3 "b" Problems

3.1b, 3.2b, 3.3b, 3.14b, 3.15b, 3.16b,
3.17Db, 3.18Db, 3.19Db

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3.1b Write definitions for the terms *fatigue failure* and *surface deterioration*.

SOLUTION 3.1b:

- *fatigue failure* = progressive fracture or breakage

- *surface deterioration* = surface deterioration, corrosion, cavitation, adhesive wear, abrasive wear, fretting, surface fatigue

3.2b Briefly discuss the importance of materials in the design of a machine component.

SOLUTION 3.2b: See the introduction -- Section 3.1

3.3b From Appendix C-1 and Appendix C-2, compare the ultimate strength, yield strength and elasticity of the following metals: (a) 1020 HR carbon steel, (b) 304A stainless steel, and (c) 2024-T4 aluminum alloy.

SOLUTION 3.3b: List the ultimate strength, yield strength and elasticity of the following metals: (a) 1020 HR carbon steel, (b) 304A stainless steel, and (c) 2024-T4 aluminum alloy and compare.

3.14b An AISI 1015 steel part is annealed to 111 Bhn. Estimate the values of Su and Sy for this part.

SOLUTION 3.14b: The tensile strength is 56,000 psi and the yield strength is 41,300 psi. See Appendix C-4a.

3.15b An AISI 1050 steel part is annealed to 187 Bhn. Estimate the values of Su and Sy for this part.

SOLUTION 3.15b: The tensile strength is 92,300 psi and the yield strength is 53,000 psi. See Appendix C-4a.

3.16b An AISI 4140 steel part is annealed to 197 Bhn. Estimate the values of Su and Sy. Compare these values with those corresponding to another AISI 4140 steel part that is normalized to 302 Bhn.

SOLUTION 3.16b: The 4140 steel part annealed to 197 Bhn has a tensile strength is 95,000 psi and a yield strength is 60,500 psi. The AISI 4140 steel part that is

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normalized to 302 Bhn has a tensile strength is 148,000 psi and a yield strength is 95,000 psi. See Appendix C-4a.

3.17Db Select a 1020 normalized steel from Appendix C-4a, and estimate Su and Sy from the given value of Brinell hardness.

SOLUTION 3.17Db: Appendix C-4a shows a Brinell hardness of 131, tensile strength of 64,000 psi, and a yield strength is 50,300 psi.

3.18Db Select a 3140 annealed steel from Appendix C-4a, and estimate Su and Sy from the given value of Brinell hardness. Compare the results to the given tensile and yield strengths.

SOLUTION 3.18Db: Appendix C-4a shows a Brinell hardness of 197, tensile strength of 100,000 psi, and a yield strength is 61,300 psi.

3.19Db Select a 1030 steel from Appendix C-4a that has properties listed for as-rolled, normalized, and annealed conditions. Estimate Su and Sy for the three conditions from the given Brinell hardness value. Compare the results to the given tensile and yield strengths.

SOLUTION 3.19Db: Appendix C-4a shows for 1030 steel,

- as-rolled: Brinell hardness of 179, tensile strength of 80,000 psi, and a yield strength is 50,000 psi.

- normalized: Brinell hardness of 149, tensile strength of 75,500 psi, and a yield strength is 50,000 psi.

- annealed: Brinell hardness of 126, tensile strength of 67,300 psi, and a yield strength is 49,500 psi.

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SOLUTION (3.1)

Known: Definitions of the terms stress, strength, yield strength, ultimate strength, elastic limit, proportional limit, modulus of elasticity, and yield point are given in Section 3.2.

Find: Write definitions of the above terms -- see Section 3.2.

Analysis:

1. The stress is the load divided by the cross-sectional area.

2. The strength is the maximum value of stress a material will carry before failure.

3. The yield strength, S_y, is the value of stress at which significant plastic yielding first occurs.

4. The ultimate strength is the maximum value of stress a material will carry before fracture for nondynamic loading.

5. The elastic limit is the highest stress the material can withstand and still return exactly to its original length when unloaded.

6. The proportional limit is the stress at which the stress-strain curve first deviates (ever so slightly) from a straight line. Below the proportional limit, Hooke's law applies.

7. The modulus of elasticity (Young's modulus) E is the constant of proportionality between stress and strain (which is the slope of the curve between the origin and the proportional limit).

8. The yield point of a material is a point for a material where appreciable yielding occurs suddenly at a clearly defined value of stress; for example, in soft steel. In other materials the onset of appreciable yielding occurs gradually, and the yield strength for these materials is determined by using the "offset method." This is illustrated in Fig. 3.1; it shows a line, offset an arbitrary amount of 0.2 percent of strain, drawn parallel to the straight-line portion of the original stress-strain diagram. Point B is the yield point of the material at 0.2 percent offset. If the load is removed after yielding to point B, the specimen exhibits a 0.2 percent permanent elongation. Yield strength corresponding to a specified (very small) offset is a standard laboratory determination, whereas elastic limit and proportional limit are not.

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SOLUTION (3.2)

Known: The Greek letter σ is employed in this textbook to denote normal stress caused by tensile, compressive, or bending loads; the Greek letter τ is utilized to denote shear stress caused by torsional or transverse shear loads; and the letter *S* designates strength properties of the material.

Find: Discuss the **purpose** in this text book of using (1) the Greek letter σ to denote normal stress, (2) the Greek letter τ to denote shear stress, and (3) the letter *S* to designate strength properties of the material.

Analysis: The purpose of using Greek letters to denote stress and the letter *S* (with appropriate subscripts) to designate *strength properties of the material* is because stress and strength are fundamentally different. Stress is a calculated term dependent on load and geometry wherein the load results in deformation or strain. Strength is a property of a material and a limiting value of stress. Strength is the maximum value of stress a material will carry before failure – yielding, fracture, pitting. For example, yield strength, S_y, is the value of stress at which significant plastic yielding first occurs. The ultimate strength, S_u, is the maximum value of stress a material will carry before fracture for nondynamic loading.

An important notation convention is observed throughout the textbook: the Greek letter σ denotes normal *stress*, which is a function of the applied loads; *S* (with appropriate subscripts) designates *strength properties of the material*.

Whereas *S* (with suitable subscripts) is used for all strength values including those for torsion or shear, the letter σ is used for normal stresses only, that is, stresses caused by tensile, compressive, or bending loads. Shear stresses, caused by torsional or transverse shear loads, are designated by the Greek letter τ.

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SOLUTION (3.3)

Known: The website http://www.matweb.com lists properties for various materials.

Find: Search this website for AISI 4340 steel, oil quenched 800°C (1470°F), 540°C (1000°F) temper, 25mm round and list values for (1) modulus of elasticity, (2) ultimate tensile strength, (3) elongation at break in %, and (4) yield strength, S_y.

Analysis: The web site http://www.matweb.com provides the following information:

(1) 29700 ksi
(2) 175100 psi
(3) 14.2% elongation at break
(4) 166100 psi

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SOLUTION (3.4)

Known: We are to determine the modulus of elasticity, ultimate tensile strength, elongation at break, and (4) density for certain carbon and alloy steels.

Find: Search the materials property database at http://www.matweb.com and list values for the (1) modulus of elasticity, E, (2) ultimate tensile strength, S_u, (3) elongation at break in %, and (4) density in g/cc, for the following: (a) AISI carbon steels: 1010 cold drawn, 1020 cold rolled, 1040 as rolled, 1050 as rolled, 1080 as rolled, and 1116 cold drawn; and (b) alloy steels: 4140 annealed, 4340 annealed, and 4620 annealed.

Analysis: (a) From **www.matweb.com** we find for AISI carbon steels:

AISI 1010, cold drawn
Density 7.87 g/cc
Tensile Strength, Ultimate 365 MPa 52900 psi
Modulus of Elasticity 205 GPa 29700 ksi
Elongation at Break 20 %

AISI 1020 Steel, cold rolled
Density 7.87 g/cc
Tensile Strength, Ultimate 420 MPa 60900 psi
Modulus of Elasticity 205 GPa 29700 ksi
Elongation at Break 15 %

AISI 1040 Steel, as rolled
Density 7.845 g/cc
Tensile Strength, Ultimate 620 MPa 89900 psi
Modulus of Elasticity 200 GPa 29000 ksi
Elongation at Break 25 %

AISI 1050 Steel, as rolled
Density 7.85 g/cc
Tensile Strength, Ultimate 725 MPa 105000 psi
Modulus of Elasticity 205 GPa 29700 ksi
Elongation at Break 20 %

AISI 1080 Steel, as rolled
Density 7.85 g/cc
Tensile Strength, Ultimate 965 MPa 140000 psi
Modulus of Elasticity 205 GPa 29700 ksi
Elongation at Break 12 %

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AISI 1116 Steel, cold drawn
Density 7.85 g/cc
Tensile Strength, Ultimate 530 MPa 76900 psi
Modulus of Elasticity 205 GPa 29700 ksi
Elongation at Break 17 %

(b) From **www.matweb.com** we find for Alloy steels:

AISI 4140 Steel, annealed at 815°C (1500°F) furnace cooled 11°C (20°F)/hour to 665°C (1230°F), air cooled, 25 mm (1 in.) round
Density 7.85 g/cc
Tensile Strength, Ultimate 655 MPa 95000 psi
Elongation at Break 25.7 %
Modulus of Elasticity 205 GPa 29700 ksi

AISI 4340 Steel, annealed, 25 mm round
Density 7.85 g/cc
Tensile Strength, Ultimate 745 MPa 108000 psi
Elongation at Break 22 %
Modulus of Elasticity 205 GPa 29700 ksi

AISI 4620 Steel, annealed, 25 mm round
Density 7.85 g/cc
Tensile Strength, Ultimate 510 MPa 74000 psi
Elongation at Break 31.3 %
Modulus of Elasticity 205 GPa 29700 ksi

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SOLUTION (3.5)

Known: We are to determine the modulus of elasticity, ultimate tensile strength, elongation at break, and (4) density for certain carbon and alloy steels.

Find: Search the materials property database at http://www.matweb.com and list the (1) modulus of elasticity, E, (2) ultimate tensile strength, S_u, (3) elongation at break in %, and (4) density in g/cc, for the following: (a) Cast iron: ASTM class 20 and class 35; (b) Aluminum alloys: 3003-H12, 3003-H18, 5052-H32, 5052-H38, 5052-O, 6061-T4, 6061-T91, and 7075-O.

Analysis: (a) From **www.matweb.com** we find for Cast iron:

Standard gray iron test bars, as cast, ASTM class 20
Density 7.15 g/cc
Tensile Strength, Ultimate 152 MPa 22000 psi
Modulus of Elasticity 66 - 97 GPa 9570 - 14100 ksi

Standard gray iron test bars, as cast, ASTM class 35
Density 7.15 g/cc
Tensile Strength, Ultimate 252 MPa 36500 psi
Modulus of Elasticity 100 - 119 GPa 14500 - 17300 ksi

(b) From **www.matweb.com** we find for Aluminum alloys:

Aluminum 3003-H12
Density 2.73 g/cc
Ultimate Tensile Strength 131 MPa 19000 psi
Elongation at Break 10 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break 20 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity 68.9 GPa 10000 ksi

Aluminum 3003-H18
Density 2.73 g/cc
Ultimate Tensile Strength 200 MPa 29000 psi
Elongation at Break 10 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Elongation at Break 4 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Modulus of Elasticity 68.9 GPa

Aluminum 5052-H32
Density 2.68 g/cc
Ultimate Tensile Strength 228 MPa 33000 psi
Elongation at Break 12 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break 18 % AA; Typical; 1/2 in. (12.7 mm) Diameter

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Modulus of Elasticity 70.3 GPa

Aluminum 5052-H38
Density 2.68 g/cc
Ultimate Tensile Strength 290 MPa 42000 psi
Elongation at Break 7 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break 8 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity 70.3 GPa

Aluminum 5052-O
Density 2.68 g/cc
Ultimate Tensile Strength 193 MPa 28000 psi
Elongation at Break 25 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break 30 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity 70.3 GPa

Aluminum 6061-T4; 6061-T451
Density 2.7 g/cc
Ultimate Tensile Strength 241 MPa 35000 psi
Elongation at Break 22 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break 25 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity 68.9 GPa

Aluminum 6061-T91
Density 2.7 g/cc
Tensile Strength, Ultimate 405 MPa 58700 psi
Elongation at Break 12 %
Modulus of Elasticity 69 GPa

Aluminum 7075-O
Density 2.81 g/cc
Ultimate Tensile Strength 228 MPa 33000 psi
Elongation at Break 16 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Elongation at Break 17 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Modulus of Elasticity 71.7 GPa

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SOLUTION (3.6)

Known: The materials to be selected have E greater than 207 GPa and S_u greater than 200 psi (1378 MPa).

Find: Identify five materials with (a) modulus of elasticity greater than steel, and (b) ultimate strength greater than 200 ksi.

Analysis:

(a) From Appendix C-1, we attempt to select the following materials with higher E values than steel, but inspection of the materials listed in the appendix of the textbook, reveals no materials with E values higher than that of steel. ■

(b) From the textbook appendices, we select the following non-steel materials with S_u values greater than 1378 MPa. ■

Material	**S_u (MPa)**
Steel	1378 MPa
Leaded beryllium copper C17300 (Appendix C-13)	1379 MPa (max)
Duranickel 301 CD aged bar (Appendix C-15)	1448 MPa (max)
Rene 95 Superalloy	1620 MPa

Comment: Inspection of the materials listed in the appendix of the textbook reveals that steel is a relatively strong and stiff material.

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SOLUTION (3.6D) -- alternate

Known: The materials to be selected have E greater than 207 GPa and S_u greater than 1378 MPa.

Find: Identify five materials with (a) modulus of elasticity greater than steel, and (b) ultimate strength greater than 200 ksi.

Analysis:

(a) From **www.matweb.com** we select the following materials with higher E values than steel:

Modulus of Elasticity, ksi, greater than 30 x 10^6 psi ■

Material	E (ksi)
Steel	30000 ksi
Beryllium, Be	40020 ksi
Chromium, Cr Recrystallized	35960 ksi
Iridium, Ir Annealed	75980 ksi
Molybdenum, Mo Annealed	47850 ksi
Osmium, Os Annealed	81200 ksi
Rhenium, Re Annealed	68005 ksi
Rhodium, Rh Annealed	52055 ksi
Ruthenium, Ru Annealed	60030 ksi
Technetium, Tc Annealed	46690 ksi
Tungsten, W	58000 ksi

(b) We select the following non-steel materials with ultimate tensile strength S_u greater than 1378 MPa (200,000 psi):

Tensile Strength, Ultimate, psi, greater than 200 ksi ■

Material	S_u (psi)
AISI Grade 18Ni (300) Maraging Steel	293625 psi

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Aged, round bar Tested longitudinal, 75 mm	
Carpenter AerMet®-for-Tooling Tool Steel Double Aged 468ºC	300005 psi
BioDur™ 316LS Stainless Medical Implant Alloy 90% Cold Worked	223445 psi
VascoMax® C-300 Specialty Steel Heat Treatment: 927°C (1700°F) + Age	285070 psi
W-25 Re Tungsten Rhenium Alloy Deformed	580000 psi
AISI A6, Type Tool Steel Austenitized 830-870ºC (1525-1600°F)	345100 psi
AISI A9, Type Tool Steel Tempered at 500ºC	319000 psi
Titanium Ti-15Mo-5Zr ST 730ºC, Aged 400ºC	246500 psi
AISI Type W2 Tool Steel Water quenched at 775ºC (1425ºF), and tempered	261000 psi
AISI Type S5 Tool Steel Austenitized 855-870ºC (1575-1600ºF) Oil quenched to 55 HRC	323350 psi
Mo-47.5 Re Molybdenum Rhenium Alloy Deformed	464000 psi
Iridium, Ir Cold-Drawn	290000 psi
Rhenium, Re Deformed	304500 psi
Rhodium, Rh Hardened	299860 psi
Technetium, Tc As-Rolled	218950 psi
Pt-20% Ni Alloy Hard	250125 psi
79Pt-15Rh-6Ru Alloy 851	300150 psi

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Pt-8% W Alloy Hard	300150 psi

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SOLUTION (3.7D)

Known: The website http://www.matweb.com lists properties for various materials.

Find: Search this website for a steel materials of your choice and list values for (1) modulus of elasticity, (2) ultimate tensile strength, (3) elongation at break in %, and (4) density in g/cc.

Analysis: The web site http://www.matweb.com provides the following information for ASI Grade 18Ni (200) Maraging Steel, Annealed.

(1) 26500 ksi
(2) 140000 psi
(3) 17% elongation at break
(4) 8 g/cc

SOLUTION (3.8)

Known: Appendix C-1 provides representative values for physical properties of common metals.

Find: List common materials in Appendix C-1 that have a lower density and a higher thermal conductivity than steel.

Analysis:

1. According to Appendix C-1, aluminum alloy, gray cast iron, magnesium alloy, titanium alloy, and zinc alloy have lower densities that steel.
2. According to Appendix, C-1, aluminum alloy, copper Beryl, brass, bronze, copper, gray cast iron, magnesium alloy, and zinc alloy have a higher thermal conductivity than steel.
3. Aluminum alloy, gray cast iron, magnesium alloy, and zinc alloy all have lower densities and have higher thermal conductivities than steel. ■

Comment: Titanium alloy has both a lower density and a lower thermal conductivity than steel.

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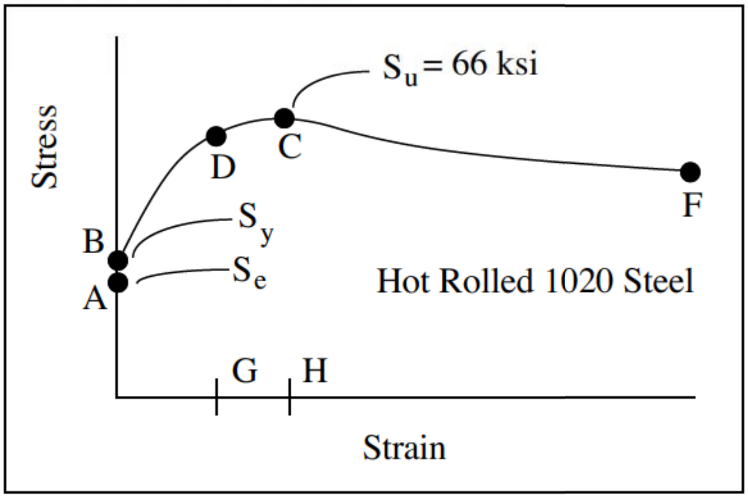
SOLUTION (3.9)

Known: The critical location of a part made from known steel is cold worked during fabrication.

Find: Estimate S_u, S_y and the ductility.

Schematic and Given Data:



Assumption: After cold working the stress-strain curve for the critical location starts at point G.

Analysis:

1. At point G in Fig. 3.2, the part has been permanently stretched to 1.1 times its initial length. Hence, its area is 1/1.1 times its original area A_o.
2. On the basis of the new area, the yield strength is $S_y = 62(1.1) = 68.2$ ksi. ■
3. The ultimate strength is $S_u = 66(1.1) = 72.6$ ksi. ■
4. At fracture, R increases to 2.5 on the graph.
5. $R = 2.5/1.1 = 2.27$
6. Using Eq. (3.3) and Eq. (3.2)

$$A_r = 1 - \frac{1}{R} = 1 - \frac{1}{2.27} = 0.56$$ ■

$$\varepsilon = R - 1 = 2.27 - 1 = 1.27 \text{ or } 127\%$$ ■

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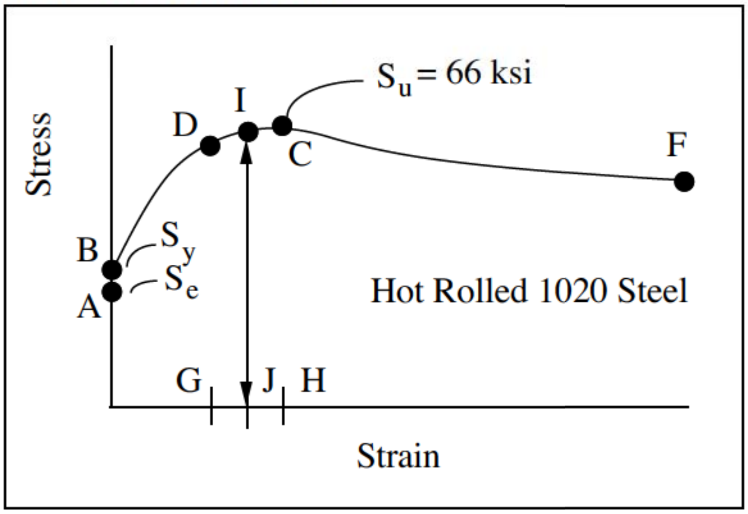
SOLUTION (3.10)

Known: The critical location of a part made from known steel is cold worked during fabrication.

Find: Estimate S_u, S_y and the ductility.

Schematic and Given Data:



Assumption: After cold working the stress-strain curve for the critical location starts at point J.

Analysis:

1. The area ratio at J is $R = A_o/A_f = 1.2$. The initial area is thus 1/1.2.
2. The yield strength is $S_y = 65(1.2) = 78$ ksi. ■
3. The ultimate strength is $S_u = 66(1.2) = 79.2$ ksi.
4. At fracture, R increases to 2.5 on the graph.
5. $R = 2.5/1.2 = 2.08$
6. Using Eq. (3.3) and Eq. (3.2)

$$A_r = 1 - \frac{1}{R} = 1 - \frac{1}{2.08} = 0.519 \qquad \varepsilon = R - 1 = 2.08 - 1 = 1.08 \text{ or } 108\%$$ ■

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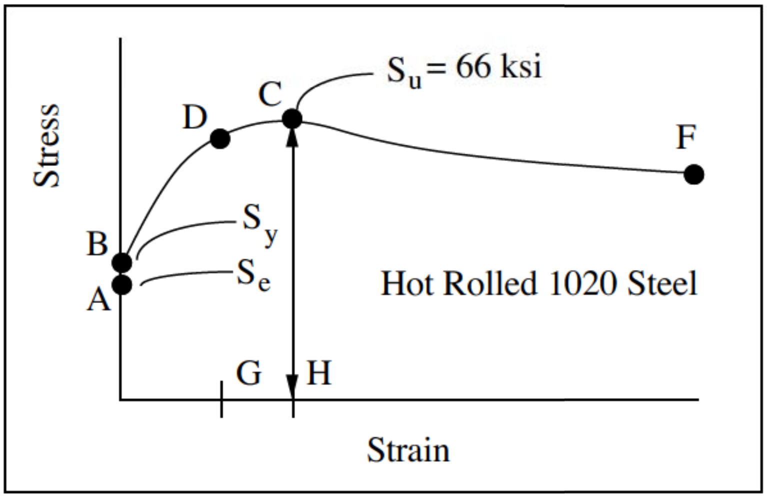
SOLUTION (3.11)

Known: A tensile specimen of a known material is loaded to the ultimate stress, then unloaded and reloaded to the ultimate stress point.

Find: Estimate the values of σ, ε, σ_T, ε_T for the first loading and the reloading.

Schematic and Given Data:



Assumption: After unloading the stress-strain curve starts at point H for the new specimen.

Analysis:

1. For the initial sample, $\sigma = 66$ ksi, $\varepsilon = 30\%$. ■
2. For Figure 3.2, $R = 1.3$ at point H.
3. From Eq. (3.4), $\sigma_T = \sigma R = (66)(1.3) = 85.8$ ksi. ■
4. From Eq. (3.5), $\varepsilon_T = \ln(1 + \varepsilon) = \ln 1.30 = 0.26 = 26\%$. ■
5. For the new specimen; $\sigma = 66(1.3) = 85.8$ ksi. ■
6. The new specimen behaves elastically, so $\varepsilon = \sigma/E = 85.8/30{,}000 = .00286$. ■
7. Within the elastic range, $\sigma_T \approx \sigma$ and $\varepsilon_T \approx \varepsilon$. Therefore $\sigma_T = 85.8$ ksi and $\varepsilon_T = 0.29\%$. ■

Comment: Note also that $\varepsilon_T = \ln(1 + \varepsilon) = \ln(1.0029) = 0.29\%$.