FOREWORD

This solution manual includes the solutions to numerical problems at the end of various chapters of the book. It does not include answers to word questions, but the appropriate sections in the book are referenced. The procedures used in the solutions are taken from the corresponding chapters and sections of the text. Each step in the solution is taken to the lowest detail level consistent with the level of the text, with a clear progression between steps. Each problem solution is self-contained, with a minimum of dependence on other solutions. The final answer of each problem is printed in bold.

The instructors are advised not to spread the solutions electronically among students in order not to limit the instructor’s choice to assign problems in future semesters.
CHAPTER 1. MATERIALS ENGINEERING CONCEPTS

1.2. Strength at rupture = 45 ksi
   Toughness = (45 x 0.003) / 2 = 0.0675 ksi

1.3. A = 0.36 in²
   σ = 138.889 ksi
   \( \varepsilon_A = 0.0035 \text{ in/in} \)
   \( \varepsilon_L = -0.016667 \text{ in/in} \)
   E = 39682 ksi
   \( \nu = 0.21 \)

1.4. A = 201.06 mm²
   σ = 0.945 GPa
   \( \varepsilon_A = 0.002698 \text{ m/m} \)
   \( \varepsilon_L = -0.000625 \text{ m/m} \)
   E = 350.3 GPa
   \( \nu = 0.23 \)

1.5. \( A = \pi d^2/4 = 28.27 \text{ in}^2 \)
   \( \sigma = \frac{P}{A} = -150,000 / 28.27 \text{ in}^2 = -5.31 \text{ ksi} \)
   E = \( \frac{\sigma}{\varepsilon} = 8000 \text{ ksi} \)
   \( \varepsilon_A = \frac{\sigma}{E} = -5.31 \text{ ksi} / 8000 \text{ ksi} = -0.0006631 \text{ in/in} \)
   \( \Delta L = \varepsilon_A L_0 = -0006631 \text{ in/in (12 in)} = -0.00796 \text{ in} \)
   \( L_f = \Delta L + L_0 = 12 \text{ in} - 0.00796 \text{ in} = 11.992 \text{ in} \)
   \( \nu = -\varepsilon_L / \varepsilon_A = 0.35 \)
   \( \varepsilon_L = \frac{\Delta d}{d_0} = -\nu \varepsilon_A = -0.35 (-0.0006631 \text{ in/in}) = 0.000232 \text{ in/in} \)
   \( \Delta d = \varepsilon_L d_0 = 0.000232 \text{ (6 in)} = 0.00139 \text{ in} \)
   \( d_f = \Delta d + d_0 = 6 \text{ in} + 0.00139 \text{ in} = 6.00139 \text{ in} \)

1.6. \( A = \pi d^2/4 = 0.196 \text{ in}^2 \)
   \( \sigma = \frac{P}{A} = 2,000 / 0.196 \text{ in}^2 = 10.18 \text{ ksi} \) (Less than the yield strength. Within the elastic region)
   E = \( \frac{\sigma}{\varepsilon} = 10,000 \text{ ksi} \)
   \( \varepsilon_A = \frac{\sigma}{E} = 10.18 \text{ ksi} / 10,000 \text{ ksi} = 0.0010186 \text{ in/in} \)
   \( \Delta L = \varepsilon_A L_0 = 0.0010186 \text{ in/in (12 in)} = 0.0122 \text{ in} \)
   \( L_f = \Delta L + L_0 = 12 \text{ in} + 0.0122 \text{ in} = 12.0122 \text{ in} \)
   \( \nu = -\varepsilon_L / \varepsilon_A = 0.33 \)
   \( \varepsilon_L = \frac{\Delta d}{d_0} = -\nu \varepsilon_A = -0.33 (0.0010186 \text{ in/in}) = -0.000336 \text{ in/in} \)
   \( \Delta d = \varepsilon_L d_0 = -0.000336 \text{ (0.5 in)} = -0.000168 \text{ in} \)
   \( d_f = \Delta d + d_0 = 0.5 \text{ in} - 0.000168 \text{ in} = 0.49998 \text{ in} \)
1.7. \( L_x = 30 \text{ mm}, L_y = 60 \text{ mm}, L_z = 90 \text{ mm} \)
\( \sigma_x = \sigma_y = \sigma_z = \sigma = 100 \text{ MPa} \)
\( E = 70 \text{ GPa} \)
\( \nu = 0.333 \)

\[ \varepsilon_x = \frac{\sigma_x - \nu (\sigma_y + \sigma_z)}{E} \]
\[ \varepsilon_x = \frac{[100 \times 10^6 - 0.333 (100 \times 10^6 + 100 \times 10^6)]}{70 \times 10^9} = 4.77 \times 10^{-4} = \varepsilon_y = \varepsilon_z = \varepsilon \]
\[ \Delta L_x = \varepsilon \times L_x = 4.77 \times 10^{-4} \times 30 = 0.01431 \text{ mm} \]
\[ \Delta L_y = \varepsilon \times L_y = 4.77 \times 10^{-4} \times 60 = 0.02862 \text{ mm} \]
\[ \Delta L_z = \varepsilon \times L_z = 4.77 \times 10^{-4} \times 90 = 0.04293 \text{ mm} \]
\[ \Delta V = \text{New volume} - \text{Original volume} = [(L_x - \Delta L_x) (L_y - \Delta L_y) (L_z - \Delta L_z)] - L_x L_y L_z 
= (30 - 0.01431) (60 - 0.02862) (90 - 0.04293)] - (30 \times 60 \times 90) = 161768 - 162000 
= 0.04293 \text{ mm}^3 \]

1.8. \( L_x = 4 \text{ in}, L_y = 4 \text{ in}, L_z = 4 \text{ in} \)
\( \sigma_x = \sigma_y = \sigma_z = \sigma = 15,000 \text{ psi} \)
\( E = 1000 \text{ ksi} \)
\( \nu = 0.49 \)

\[ \varepsilon_x = \frac{\sigma_x - \nu (\sigma_y + \sigma_z)}{E} \]
\[ \varepsilon_x = \frac{[15 - 0.49 (15 + 15)]}{1000} = 0.0003 = \varepsilon_y = \varepsilon_z = \varepsilon \]
\[ \Delta L_x = \varepsilon \times L_x = 0.0003 \times 15 = 0.0045 \text{ in} \]
\[ \Delta L_y = \varepsilon \times L_y = 0.0003 \times 15 = 0.0045 \text{ in} \]
\[ \Delta L_z = \varepsilon \times L_z = 0.0003 \times 15 = 0.0045 \text{ in} \]
\[ \Delta V = \text{New volume} - \text{Original volume} = [(L_x - \Delta L_x) (L_y - \Delta L_y) (L_z - \Delta L_z)] - L_x L_y L_z 
= (15 - 0.0045) (15 - 0.0045) (15 - 0.0045)] - (15 \times 15 \times 15) = 3371.963 - 3375 
= 0.3037 \text{ in}^3 \]

1.9. \( \varepsilon = 0.3 \times 10^{-16} \sigma^3 \)

At \( \sigma = 50,000 \text{ psi}, \varepsilon = 0.3 \times 10^{-16} (50,000)^3 = 3.75 \times 10^{-3} \text{ in./in.} \)

Secant Modulus = \( \frac{\Delta \sigma}{\Delta \varepsilon} = \frac{50,000}{3.75 \times 10^{-3}} = 1.33 \times 10^7 \text{ psi} \)

\( \frac{d \varepsilon}{d \sigma} = 0.9 \times 10^{-16} \sigma^2 \)

At \( \sigma = 50,000 \text{ psi}, \frac{d \varepsilon}{d \sigma} = 0.9 \times 10^{-16} (50,000)^2 = 2.25 \times 10^{-7} \text{ in.}^2/\text{lb} \)

Tangent modulus = \( \frac{d \sigma}{d \varepsilon} = \frac{1}{2.25 \times 10^{-7}} = 4.44 \times 10^6 \text{ psi} \)
1.11. \( \varepsilon_{\text{lateral}} = \frac{-3.25 \times 10^{-4}}{1} = -3.25 \times 10^{-4} \text{ in./in.} \)

\( \varepsilon_{\text{axial}} = \frac{2 \times 10^{-3}}{2} = 1 \times 10^{-3} \text{ in./in.} \)

\( \nu = \frac{\varepsilon_{\text{lateral}}}{\varepsilon_{\text{axial}}} = \frac{-3.25 \times 10^{-4}}{1 \times 10^{-3}} = 0.325 \)

1.12. \( \varepsilon_{\text{lateral}} = 0.05 / 50 = 0.001 \text{ in./in.} \)

\( \varepsilon_{\text{axial}} = \nu \times \varepsilon_{\text{lateral}} = 0.33 \times 0.001 = 0.00303 \text{ in.} \)

\( \Delta d = \varepsilon_{\text{axial}} \times d_0 = -0.00825 \text{ in. (Contraction)} \)

1.13. \( L = 380 \text{ mm} \)

\( D = 10 \text{ mm} \)

\( P = 24.5 \text{ kN} \)

\( \sigma = \frac{P}{A} = \frac{P}{\pi r^2} \)

\( \sigma = 24,500 \text{ N/}\pi (5 \text{ mm})^2 = 312,000 \text{ N/mm}^2 = 312 \text{ MPa} \)

\( \delta = \frac{PL}{AE} = \frac{24,500 \text{ lbx}380 \text{ mm}}{\pi(5 \text{ mm})^2 \frac{E(\text{kPa})}{E(\text{MPa})}} = 118,539 \text{ mm} \)

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Stress (MPa)</th>
<th>( \delta ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>110,000</td>
<td>248</td>
<td>289</td>
<td>312</td>
<td>1.078</td>
</tr>
<tr>
<td>Al. alloy</td>
<td>70,000</td>
<td>255</td>
<td>420</td>
<td>312</td>
<td>1.693</td>
</tr>
<tr>
<td>Steel</td>
<td>207,000</td>
<td>448</td>
<td>551</td>
<td>312</td>
<td>0.573</td>
</tr>
<tr>
<td>Brass alloy</td>
<td>101,000</td>
<td>345</td>
<td>420</td>
<td>312</td>
<td>1.174</td>
</tr>
</tbody>
</table>

The problem requires the following two conditions:

a) No plastic deformation \( \Rightarrow \) Stress < Yield Strength  
b) Increase in length, \( \delta < 0.9 \text{ mm} \)

The only material that satisfies both conditions is steel.

1.14. a. \( E = \sigma / \varepsilon = 40,000 / 0.004 = 10 \times 10^6 \text{ psi} \)

b. Tangent modulus at a stress of 45,000 psi is the slope of the tangent at that stress = \( 4.7 \times 10^6 \text{ psi} \)

c. Yield stress using an offset of 0.002 strain = \( 49,000 \text{ psi} \)

d. Maximum working stress = Failure stress / Factor of safety = 49,000 / 1.5 = \( 32,670 \text{ psi} \)
1.15. a. Modulus of elasticity within the linear portion = 20,000 ksi. 
   b. Yield stress at an offset strain of 0.002 in./in. ≈ 70.0 ksi 
   c. Yield stress at an extension strain of 0.005 in/in. ≈ 69.5 ksi 
   d. Secant modulus at a stress of 62 ksi. ≈ 18,000 ksi 
   e. Tangent modulus at a stress of 65 ksi. ≈ 6,000 ksi 

1.16. a. Modulus of resilience = the area under the elastic portion of the stress strain curve = \( \frac{1}{2} \times (50 \times 0.0025) \approx 0.0625 \text{ ksi} \) 
   b. Toughness = the area under the stress strain curve (using the trapezoidal integration technique) ≈ 0.69 ksi 
   c. \( \sigma = 40 \, \text{ksi} \), this stress is within the elastic range, therefore, \( E = 20,000 \, \text{ksi} \) 
      \( \varepsilon_{axial} = \frac{40}{20,000} = 0.002 \, \text{in./in.} \) 
      \[ \nu = \frac{\varepsilon_{lateral}}{\varepsilon_{axial}} = \frac{-0.00057}{0.002} = 0.285 \] 
   d. The permanent strain at 70 ksi = 0.0018 in./in. 

1.17. 

<table>
<thead>
<tr>
<th></th>
<th>Material A</th>
<th>Material B</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Proportional limit</td>
<td>51 ksi</td>
<td>40 ksi</td>
</tr>
<tr>
<td>b. Yield stress at an offset strain of 0.002 in./in.</td>
<td>63 ksi</td>
<td>52 ksi</td>
</tr>
<tr>
<td>c. Ultimate strength</td>
<td>132 ksi</td>
<td>73 ksi</td>
</tr>
<tr>
<td>d. Modulus of resilience</td>
<td>0.065 ksi</td>
<td>0.07 ksi</td>
</tr>
<tr>
<td>e. Toughness</td>
<td>8.2 ksi</td>
<td>7.5 ksi</td>
</tr>
<tr>
<td>f.</td>
<td></td>
<td>Material B is more ductile as it undergoes more deformation before failure</td>
</tr>
</tbody>
</table>

1.18. Assume that the stress is within the linear elastic range. 
\[ \sigma = \varepsilon \cdot E = \frac{\delta E}{l} = \frac{0.3 \times 16,000}{10} = 480 \, \text{ksi} \] 
Thus \( \sigma > \sigma_{\text{yield}} \) 
Therefore, the applied stress is not within the linear elastic region and it is not possible to compute the magnitude of the load that is necessary to produce the change in length based on the given information.
1.19. Assume that the stress is within the linear elastic range.

\[ \sigma = \varepsilon E \frac{\Delta E}{l} = \frac{7.6 \times 10^5}{250} = 3.192 \text{ MPa} \]

Thus \( \sigma > \sigma_{\text{yield}} \)

Therefore, the applied stress is not within the linear elastic region and it is not possible to compute the magnitude of the load that is necessary to produce the change in length based on the given information.

1.20. At \( \sigma = 60,000 \text{ psi}, \varepsilon = \sigma / E = 60,000 / (30 \times 10^6) = 0.002 \text{ in./in.} \)

a. For a strain of 0.001 in./in.: 
\[ \sigma = \varepsilon E = 0.001 \times 30 \times 10^6 = 30,000 \text{ psi} \] (for both i and ii)

b. For a strain of 0.004 in./in.: 
\[ \sigma = 60,000 \text{ psi} \] (for i)
\[ \sigma = 60,000 + 2 \times 10^6 (0.004 - 0.002) = 64,000 \text{ psi} \] (for ii)

1.21. a. Slope of the elastic portion = 600/0.003 = 2 \times 10^5 \text{ MPa}

Slope of the plastic portion = (800-600)/(0.07-0.003) = 2,985 MPa

Strain at 650 MPa = 0.003 + (650-600)/2,985 = 0.0198 m/m

Permanent strain at 650 MPa = 0.0198 – 650/(2 \times 10^5) = 0.0165 m/m

b. Percent increase in yield strength = = 100(650-600)/600 = 8.3%

c. The strain at 625 MPa = 625/(2 \times 10^5) = 0.003125 m/m

This strain is elastic.

1.22. See Sections 1.2.3, 1.2.4 and 1.2.5.
1.23. The stresses and strains can be calculated as follows:

\[ \sigma = \frac{P}{A_0} = \frac{150}{\pi \times 2^2} = 11.94 \text{ psi} \]

\[ \varepsilon = \frac{(H_0 - H)}{H_0} = \frac{(6 - H)}{6} \]

The stresses and strains are shown in the following table:

<table>
<thead>
<tr>
<th>Time (min.)</th>
<th>H (in.)</th>
<th>Strain (in./in.)</th>
<th>Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>0.00000</td>
<td>11.9366</td>
</tr>
<tr>
<td>0.01</td>
<td>5.9916</td>
<td>0.00140</td>
<td>11.9366</td>
</tr>
<tr>
<td>2</td>
<td>5.987</td>
<td>0.00217</td>
<td>11.9366</td>
</tr>
<tr>
<td>5</td>
<td>5.9833</td>
<td>0.00278</td>
<td>11.9366</td>
</tr>
<tr>
<td>10</td>
<td>5.9796</td>
<td>0.00340</td>
<td>11.9366</td>
</tr>
<tr>
<td>20</td>
<td>5.9753</td>
<td>0.00412</td>
<td>11.9366</td>
</tr>
<tr>
<td>30</td>
<td>5.9725</td>
<td>0.00458</td>
<td>11.9366</td>
</tr>
<tr>
<td>40</td>
<td>5.9708</td>
<td>0.00487</td>
<td>11.9366</td>
</tr>
<tr>
<td>50</td>
<td>5.9696</td>
<td>0.00507</td>
<td>11.9366</td>
</tr>
<tr>
<td>60</td>
<td>5.9688</td>
<td>0.00520</td>
<td>11.9366</td>
</tr>
<tr>
<td>60.01</td>
<td>5.9772</td>
<td>0.00380</td>
<td>0.0000</td>
</tr>
<tr>
<td>62</td>
<td>5.9807</td>
<td>0.00322</td>
<td>0.0000</td>
</tr>
<tr>
<td>65</td>
<td>5.9841</td>
<td>0.00265</td>
<td>0.0000</td>
</tr>
<tr>
<td>70</td>
<td>5.9879</td>
<td>0.00202</td>
<td>0.0000</td>
</tr>
<tr>
<td>80</td>
<td>5.9926</td>
<td>0.00123</td>
<td>0.0000</td>
</tr>
<tr>
<td>90</td>
<td>5.9942</td>
<td>0.00097</td>
<td>0.0000</td>
</tr>
<tr>
<td>100</td>
<td>5.9954</td>
<td>0.00077</td>
<td>0.0000</td>
</tr>
<tr>
<td>110</td>
<td>5.9959</td>
<td>0.00068</td>
<td>0.0000</td>
</tr>
<tr>
<td>120</td>
<td>5.9964</td>
<td>0.00060</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
a. Stress versus time plot for the asphalt concrete sample

![Stress versus time plot](image)

b. Elastic strain = 0.0014 in./in.

c. The permanent strain at the end of the experiment = 0.0006 in./in.

d. The phenomenon of the change of specimen height during static loading is called **creep** while the phenomenon of the change of specimen height during unloading called is called **recovery**.
1.24. See Figure 1.12(a).

1.25. See Section 1.2.7.

1.27. a. For \( P = 5 \) kN
   \[
   \text{Stress} = \frac{P}{A} = \frac{5000}{\pi \times 5^2} = 63.7 \text{ N/mm}^2 = 63.7 \text{ MPa}
   \]
   \[
   \frac{\text{Stress}}{\text{Strength}} = \frac{63.7}{290} = 0.22
   \]
   From Figure 1.16, an unlimited number of repetitions can be applied without fatigue failure.

b. For \( P = 11 \) kN
   \[
   \text{Stress} = \frac{P}{A} = \frac{11000}{\pi \times 5^2} = 140.1 \text{ N/mm}^2 = 140.1 \text{ MPa}
   \]
   \[
   \frac{\text{Stress}}{\text{Strength}} = \frac{140.1}{290} = 0.48
   \]
   From Figure 1.16, \( N \approx 700 \)

1.28. See Section 1.2.8.

1.29.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>7.9</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.7</td>
</tr>
<tr>
<td>Aggregates</td>
<td>2.6 - 2.7</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.4</td>
</tr>
<tr>
<td>Asphalt cement</td>
<td>1 - 1.1</td>
</tr>
</tbody>
</table>

1.30. See Section 1.3.2.

1.31. \( \delta L = \alpha L \times \Delta T \times L = 12.5 \times 10^{-6} \times (115-15) \times 200/1000 = 0.00025 \text{ m} = 250 \text{ microns} \)

Rod length = \( L + \delta L = 200,000 + 250 = 200,250 \text{ microns} \)

Compute change in diameter linear method
\[ \Delta d = \alpha_d \times \Delta T \times d = 12.5 \times 10^{-6} \times (115-15) \times 20 = 0.025 \text{ mm} \]
Final \( d = 20.025 \text{ mm} \)

Compute change in diameter volume method
\[ \Delta V = \alpha V \times \Delta T \times V = (3 \times 12.5 \times 10^{-6}) \times (115-15) \times \pi \times (10/1000)^2 \times 200/1000 = 2.3562 \times 10^{11} \text{ m}^3 \]
Rod final volume = \( V + \Delta V = \pi r^2 L + \Delta V = 6.28319 \times 10^{13} + 2.3562 \times 10^{11} = 6.31 \times 10^{13} \text{ m}^3 \)
Final \( d = 20.025 \text{ mm} \)

There is no stress acting on the rod because the rod is free to move.
1.32. Since the rod is snugly fitted against two immovable nonconducting walls, the length of the rod will not change, \( L = 200 \text{ mm} \)

From problem 1.25, \( \delta L = 0.00025 \text{ m} \)
\[ \varepsilon = \frac{\delta L}{L} = \frac{0.00025}{0.2} = 0.00125 \text{ m/m} \]
\[ \sigma = \varepsilon E = 0.00125 \times 207,000 = 258.75 \text{ MPa} \]
The stress induced in the bar will be compression.

1.33. a. The change in length can be calculated using Equation 1.9 as follows:
\[ \delta L = \alpha \cdot \Delta T \cdot L = 1.1 \times 10^{-5} \times (5 - 40) \times 4 = -0.00154 \text{ m} \]

b. The tension load needed to return the length to the original value of 4 meters can be calculated as follows:
\[ \varepsilon = \frac{\delta L}{L} = -0.00154/4 = -0.000385 \text{ m/m} \]
\[ \sigma = \varepsilon E = -0.000385 \times 200,000 = -77 \text{ MPa} \]
\[ P = \sigma A = -77 \times (100 \times 50) = -385,000 \text{ N} = -385 \text{ kN (tension)} \]

c. Longitudinal strain under this load = \( 0.000385 \text{ m/m} \)

1.34. If the bar was fixed at one end and free at the other end, the bar would have contracted and no stresses would have developed. In that case, the change in length can be calculated using Equation 1.9 as follows.
\[ \delta L = \alpha \cdot \Delta T \cdot L = 0.000005 \times (0 - 100) \times 50 = -0.025 \text{ in.} \]
\[ \varepsilon = \frac{\delta L}{L} = 0.025 / 50 = 0.0005 \text{ in./in.} \]

Since the bar is fixed at both ends, the length of the bar will not change. Therefore, a tensile stress will develop in the bar as follows.
\[ \sigma = \varepsilon E = -0.0005 \times 5,000,000 = -2,500 \text{ psi} \]

Thus, the tensile strength should be larger than \( 2,500 \text{ psi} \) in order to prevent cracking.

1.36 See Section 1.7.

1.37 See Section 1.7.1

1.38. \( H_0: \mu \geq 32.4 \text{ MPa} \)
\( H_1: \mu < 32.4 \text{ MPa} \)
\[ \alpha = 0.05 \]
\[ T_0 = \frac{\bar{x} - \mu}{\sigma / \sqrt{n}} = -3 \]

Degree of freedom = \( \nu = n - 1 = 15 \)
From the statistical t-distribution table, \( T_{\alpha, \nu} = T_{0.05, 15} = -1.753 \)
\[ T_0 < T_{\alpha, \nu} \]
Therefore, reject the hypothesis. The contractor’s claim is not valid.
1.39. H₀: \( \mu \geq 5,000 \text{ psi} \)
H₁: \( \mu < 5,000 \text{ psi} \)
\( \alpha = 0.05 \)
\[
T_0 = \frac{\bar{x} - \mu}{\left(\frac{\sigma}{\sqrt{n}}\right)} = -2.236
\]
Degree of freedom = \( \nu = n - 1 = 19 \)
From the statistical t-distribution table, \( T_{\alpha, \nu} = T_{0.05, 19} = -1.729 \)
\( T_0 < T_{\alpha, \nu} \)
Therefore, reject the hypothesis. The contractor’s claim is not valid.

1.40. \[
x = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{\sum_{i=1}^{20} x_i}{20} = \frac{113,965}{20} = 5,698.25 \text{ psi}
\]
\[
s = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}\right)^{1/2} = \left(\frac{\sum_{i=1}^{20} (x_i - 5698.25)^2}{20 - 1}\right)^{1/2} = 571.35 \text{ psi}
\]

Coefficient of Variation = 100 \( \left(\frac{s}{x}\right) = 100 \left(\frac{571.35}{5698.25}\right) = 10.03\% \)

b. The control chart is shown below.

![Control Chart](image)

The target value is any value above the specification limit of 5,000 psi. The plant production is meeting the specification requirement.