Calculate the force required in direct extrusion of 1100-O aluminum from a diameter of 6 in. to 2 in. Assume that the redundant work is 30% of the ideal work of deformation, and the friction work is 25% of the total work of deformation.

The extrusion ratio is $R = 6^2/2^2 = 9$, and thus the true strain is $\epsilon = \ln(9) = 2.20$. For 1100-O aluminum, we have from Table 2.3 on p. 37, $K = 180$ MPa $= 26{,}000$ psi and $n = 0.20$. Therefore, from Eq. (2.60) on p. 71, the average flow stress is

$$\bar{Y} = \frac{K\epsilon^n}{n+1} = \frac{(26{,}000)(2.20)^{0.20}}{1.20} = 25{,}360 \text{ psi}$$

The ideal extrusion pressure is, from Eq. (6.54) on p. 310,

$$p = Y \ln R = (25{,}360) \ln 9 = 55{,}700 \text{ psi}$$

The ideal extrusion force is then

$$F = pA = \frac{\pi p d^2}{4} = \frac{\pi(55{,}700)(6)^2}{4}$$

or $F = 1.57 \times 10^6$ lb. The total force is the sum of the forces for ideal, friction, and redundant deformation. In this case, we can write

$$F_{\text{total}} = F_{\text{ideal}} + 0.30F_{\text{ideal}} + 0.25F_{\text{total}}$$

Therefore,

$$F_{\text{total}} = 1.73F_{\text{ideal}} = 2.72 \times 10^6 \text{ lb} = 1360 \text{ tons}$$