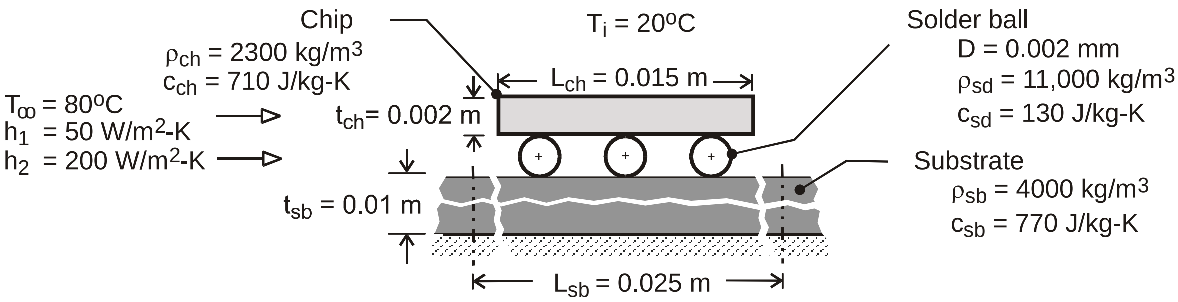
PROBLEM 5.39

KNOWN: Dimensions, initial temperature and thermophysical properties of chip, solder and substrate. Temperature and convection coefficient of heating agent.

FIND: (a) Time constants and temperature histories of chip, solder and substrate when heated by an air stream. Time corresponding to maximum stress on a solder ball. (b) Reduction in time associated with using a dielectric liquid to heat the components.

SCHEMATIC:



ASSUMPTIONS: (1) Lumped capacitance analysis is valid for each component, (2) Negligible heat transfer between components, (3) Negligible reduction in surface area due to contact between components, (4) Negligible radiation for heating by air stream, (5) Uniform convection coefficient among components, (6) Constant properties.

ANALYSIS: (a) From Eq. (5.7), $\tau_t = (\rho Vc)/hA$

Chip: $V = \left(L_{ch}^2\right)t_{ch} = (0.015\text{m})^2(0.002\text{m}) = 4.50\times10^{-7}\,\text{m}^3, A_s = \left(2L_{ch}^2 + 4L_{ch}t_{ch}\right)$

$$= 2(0.015\text{m})^2 + 4(0.015\text{m})0.002\text{m} = 5.70\times10^{-4}\,\text{m}^2$$

$$\tau_t = \frac{2300\,\text{kg/m}^3 \times 4.50\times10^{-7}\,\text{m}^3 \times 710\,\text{J/kg}\cdot\text{K}}{50\,\text{W/m}^2\cdot\text{K}\times 5.70\times10^{-4}\,\text{m}^2} = 25.8\text{s} \qquad <$$

Solder: $V = \pi D^3/6 = \pi(0.002\text{m})^3/6 = 4.19\times10^{-9}\,\text{m}^3, A_s = \pi D^2 = \pi(0.002\text{m})^2 = 1.26\times10^{-5}\,\text{m}^2$

$$\tau_t = \frac{11{,}000\,\text{kg/m}^3 \times 4.19\times10^{-9}\,\text{m}^3 \times 130\,\text{J/kg}\cdot\text{K}}{50\,\text{W/m}^2\cdot\text{K}\times 1.26\times10^{-5}\,\text{m}^2} = 9.5\text{s} \qquad <$$

Substrate: $V = \left(L_{sb}^2\,t_{sb}\right) = (0.025\text{m})^2(0.01\text{m}) = 6.25\times10^{-6}\,\text{m}^3, A_s = L_{sb}^2 = (0.025\text{m})^2 = 6.25\times10^{-4}\,\text{m}^2$

$$\tau_t = \frac{4000\,\text{kg/m}^3 \times 6.25\times10^{-6}\,\text{m}^3 \times 770\,\text{J/kg}\cdot\text{K}}{50\,\text{W/m}^2\cdot\text{K}\times 6.25\times10^{-4}\,\text{m}^2} = 616.0\text{s} \qquad <$$

Substituting Eq. (5.7) into (5.5) and recognizing that $(T - T_i)/(T_\infty - T_i) = 1 - (\theta/\theta_i)$, in which case $(T - T_i)/(T_\infty - T_i) = 0.99$ yields $\theta/\theta_i = 0.01$, it follows that the time required for a component to experience 99% of its maximum possible temperature rise is

$$t_{0.99} = \tau\ln(\theta_i/\theta) = \tau\ln(100) = 4.61\tau$$

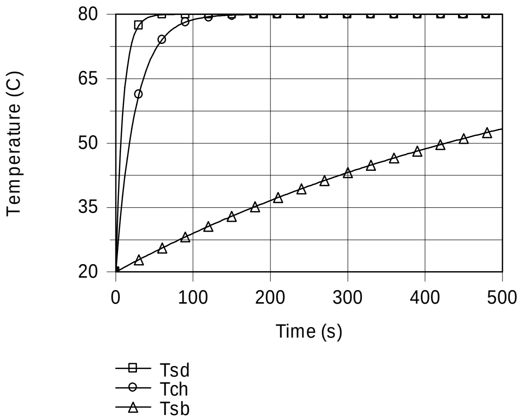
Hence,

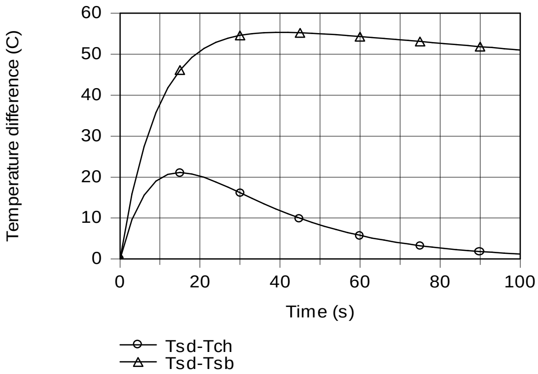
Chip: $t = 118.9\text{s}$, *Solder*: $t = 43.8\text{s}$, *Substrate*: $t = 2840$ $<$

Continued …

PROBLEM 5.39 (Cont.)

Histories of the three components and temperature differences between a solder ball and its adjoining components are shown below.





Commensurate with their time constants, the fastest and slowest responses to heating are associated with the solder and substrate, respectively. Accordingly, the largest temperature difference is between these two components, and it achieves a maximum value of 55°C at

$$t(\text{maximum stress}) \approx 40\text{s} \qquad <$$

(b) With the 4-fold increase in h associated with use of a dielectric liquid to heat the components, the time constants are each reduced by a factor of 4, and the times required to achieve 99% of the maximum temperature rise are

Chip: $t = 29.5\text{s}$, *Solder*: $t = 11.0\text{s}$, *Substrate*: $t = 708\text{s}$ $<$

The time savings is approximately 75%.

COMMENTS: The foregoing analysis provides only a first, albeit useful, approximation to the heating problem. Several of the assumptions are highly approximate, particularly that of a uniform convection coefficient. The coefficient will vary between components, as well as on the surfaces of the components. Also, because the solder balls are flattened, there will be a reduction in surface area exposed to the fluid for each component, as well as heat transfer between components, which reduces differences between time constants for the components.