HW 7

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Problem 10.1. For an aluminum alloy, the activation energy for crystal growth is 120 kJ/mol. By what factor would the rate of crystal growth change by dropping the alloy temperature from 500°C to room temperature (25°C)?

Let $T_1 = 500$°C and $T_2 = 25$°C. Activation energy $Q = 120$kJ and the gas constant $k = 8.314$J/(mol*K).

$$\frac{\dot{G}_1 = Ce^{\frac{-Q}{RT_1}}}{\dot{G}_2 = Ce^{\frac{-Q}{RT_2}}} \Rightarrow \frac{\dot{G}_1 = e^{\frac{Q}{kT_2}}}{\dot{G}_2 = e^{\frac{Q}{kT_1}}} \Rightarrow \frac{\dot{G}_1}{\dot{G}_2} = e^{\frac{Q}{R}(\frac{1}{T_2} - \frac{1}{T_1})} \Rightarrow \dot{G}_1 = \dot{G}_2 e^{\frac{Q}{R}(\frac{1}{T_2} - \frac{1}{T_1})}$$

$$\dot{G}_1 = \dot{G}_2 e^{\frac{Q}{R}(\frac{1}{T_2} - \frac{1}{T_1})} \Rightarrow \dot{G}_1 = \dot{G}_2 e^{\frac{120000}{8.314}(\frac{1}{25+273} - \frac{1}{500+273})} \Rightarrow \dot{G}_1 = 8.43 \times 10^{12} \dot{G}_2$$

Problem 10.11. (a) A carbon steel with 1.13 wt% C is given the following heat treatment: (i) instantaneously quenched to 200°C, (ii) held for 1 day, and (iii) cooled slowly to room temperature. What is the resulting microstructure? **(b)** What microstructure would result if a carbon steel with 0.5 wt% C were given exactly the same heat treatment?

(a) Since the temperature is held at 200°C, the steel does not enter the martensite region, instead it stays on the border between bainite and martenite. Now at 1 day, the steel is fully in the Bainite region since it is at the solidification temperature. This means the steel microstructure must be 100% Bainite.

(b) Looking at Figure 10.16 in the book [1], we can see that a temperature of 200° is near the 90% martensite line. So our sample will contain 90% martensite and obtain 10% of the original austenite.

Problem 10.21. It is worth noting that in TTT diagrams such as Figure 10.7, the 50% completion (dashed line) curve lies roughly midway between the onset (1%) curve and completion (99%) curve. It is also worth noting that the progress of transformation is not linear, but instead is sigmoidal (s-shaped) in nature. For example, careful observation of Figure 10.7 at 500°C show that 1%, 50%, and 99% completion occur at 0.9 s, 3.0 s, and 9.0 s, respectively. Intermediate completion data, however, can be given as follows:

% completion	**t(s)**
20	2.3
40	2.9
60	3.2
80	3.8

Plot the % completion at 500°C versus log t to illustrate the sigmoidal nature of the transformation.

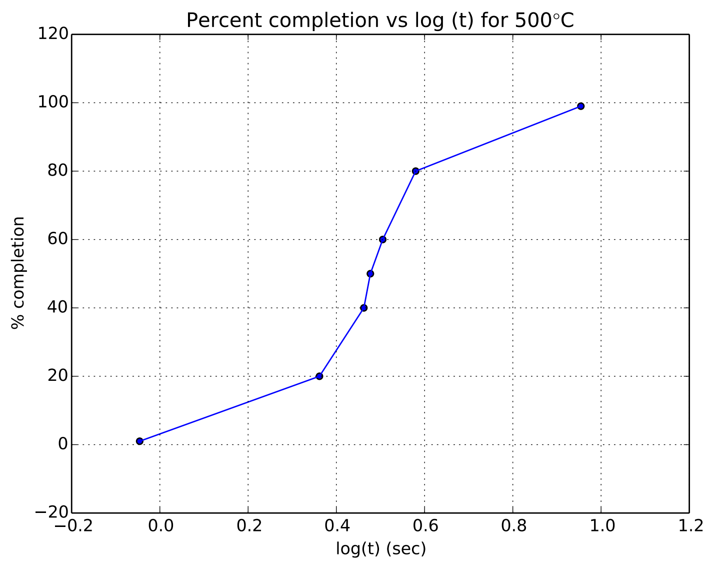

Figure 1:

Problem 10.31. In heat-treating a complex-shaped part made from a 5140 steel, a final quench in stirred oil leads to a hardness of Rockwell C30 at 3 mm beneath the surface. This hardness is unacceptable, as design specifications require a hardness of Rockwell C45 at that point. Select an alloy substitution to provide this hardness, assuming the heat treatment must remain the same.

Looking at Fig 10.24 in the book [1], A rockwell C value of 30 corresponds to 10/16 inch for the quench distance of 5140. According to the problem, we want to pick a material that has this same quench distance, 10/16 inch, but offers us atleast a rockwell hardness of C45. The only two alloys that have a rockwell C value of 45 or great when the quench distance is 10/16 inch are 4340 and 9840 Steel.

Problem 10.41. Recrystallization is a thermally activated process and, as such, can be characterized by the Arrhenius expression (Equation 5.1). As a first approximation, we can treat ${t_R}^{-1}$ as a "rate," where t_R is the time necessary to fully recrystallize the microstructure. For a 75% cold-worked aluminum alloy, t_R is 100 hours at 250°C and only 10 hours at 280°C. Calculate the activation energy for this recrystallization process. (Note Problem 10.35, in which a similar method was applied to the case of precipitation hardening.)

Given that $t_R1 = 100$ hours, $t_R2 = 10$ hours, $T_1 = 250°C$, and $T_2 = 280°C$, we can solve this problem the same way we did for problem 1 in this hw.

$$\frac{{t_{R1}}^{-1}}{{t_{R2}}^{-1}} = \frac{Ce^{\frac{-Q}{RT_1}}}{Ce^{\frac{-Q}{RT_2}}} \Rightarrow \frac{\frac{1}{100}}{\frac{1}{10}} = \frac{e^{\frac{Q}{RT_2}}}{e^{\frac{Q}{RT_1}}} \Rightarrow \frac{1}{10} = e^{\frac{Q}{R}(\frac{1}{T_2}-\frac{1}{T_1})} \Rightarrow \ln 0.1 = \frac{Q}{R}(\frac{1}{T_2} - \frac{1}{T_1})$$

$$\ln 0.1 = \frac{Q}{R}(\frac{1}{T_2} - \frac{1}{T_1}) \Rightarrow Q = \frac{RT_1T_2 \ln 0.1}{T_1 - T_2} \Rightarrow Q = \frac{(8.314)(\ln 0.1)(523)(553)}{523 - 553} = 185\text{kJ}$$

1 References

1. James F. Shackelford, Introduction to Materials Science for Engineers, Seventh Edition, Pearson Higher Education, Inc., Upper Saddle River, New Jersey (2009).