Name:

Student Id. #

Question 1: *{5 marks}*

A cylindrical rod of copper originally 17.0 mm in diameter is to be cold worked by drawing; the circular cross section will be maintained during deformation. A cold-worked yield strength in excess of 250 MPa and a ductility of at least 12%EL are desired. Furthermore, the final diameter must be 10.0 mm. By using the graphs below explain how this may be accomplished.

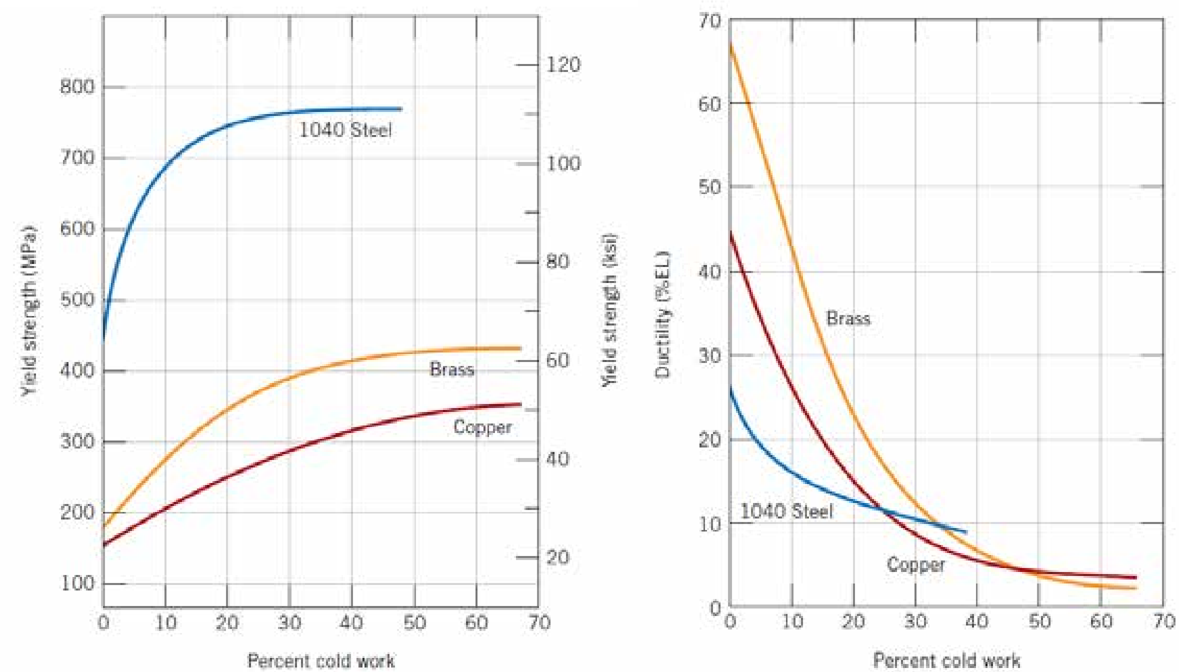

Figure 1 - For 1040 steel, brass, and copper, the increase in yield strength and the decrease in ductility (%EL) with percent cold work

Solution:

Let us first calculate the percent cold work and attendant yield strength and ductility if the drawing is carried out without interruption. From Equation 7.8

$$\%CW = \frac{A_0 - A_d}{A_0} \times 100 = \frac{\pi(\frac{d_0}{2})^2 - \pi(\frac{d_d}{2})^2}{\pi(\frac{d_0}{2})^2} \times 100$$

$$= \frac{\pi(\frac{17.0\ mm}{2})^2 - \pi(\frac{10.0\ mm}{2})^2}{\pi(\frac{17.0\ mm}{2})^2} \times 100 = 65.4\%CW$$

At 65.4%CW, the copper will have a yield strength on the order of 350 MPa Figure 7.19a, which is adequate; however, the ductility will be about 4%EL, Figure 7.19c, which is insufficient. Instead of performing the drawing in a single operation, let us initially **draw** some fraction of the total deformation, and then anneal to **recrystallize**, and, finally, **cold work** the material a second time in order to achieve the final diameter, yield strength, and ductility.

Reference to Figure 7.19a indicates that 21%CW is necessary to give a yield strength of 250 MPa. Similarly, a maximum of 23%CW is possible for 12%EL [Figure 7.19c]. The average of these two values is 22%CW, which we will use in the calculations. Thus, to achieve both the specified yield strength and ductility, the copper must be deformed to 22%CW. If the final diameter after the first drawing and initial diameter for the second drawing is $d_{0'}$, then using Equation 7.8

$$22\%CW = \frac{\pi(\frac{d_0'}{2})^2 - \pi(\frac{10.0\ mm}{2})^2}{\pi(\frac{d_0'}{2})^2} \times 100$$

And, solving for d_0' from the above expression yields

$$d_0' = \frac{10.0\ mm}{\sqrt{1 - \frac{22\%CW}{100}}} = 11.3\ mm$$

<u>Question 2:</u> *{5 marks}*

Copper-rich copper–beryllium alloys are precipitation hardenable. After consulting the portion of the phase diagram given below, do the following:

(a) Specify the range of compositions over which these alloys may be precipitation hardened.

(b) Briefly describe the heat-treatment procedures (in terms of temperatures) that would be used to precipitation harden an alloy having a composition of your choosing, yet lying within the range given for part (a).

(c) Sketch the expected microstructure.

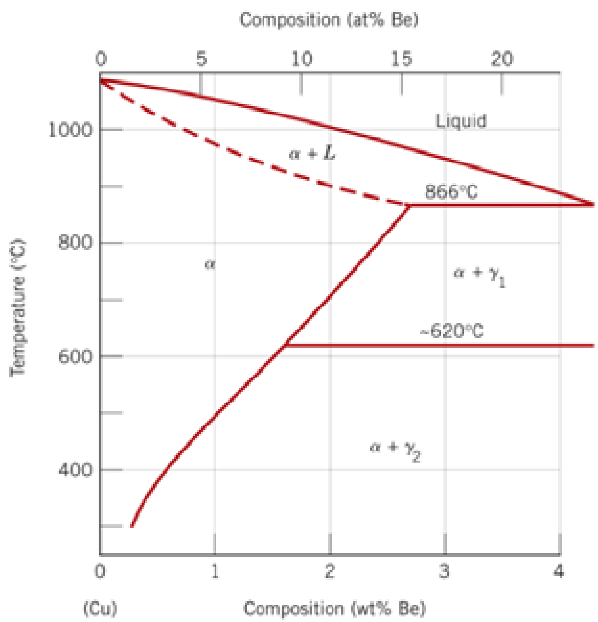

Figure 2 - Cu-rich side of Cu-Be binary phase diagram

Solution

This problem is concerned with the precipitation-hardening of copper-rich Cu-Be alloys. It is necessary for us to use the Cu-Be phase diagram, which is shown above.

(a) The range of compositions over which these alloys may be precipitation hardened is between approximately 0.2 wt% Be (the maximum solubility of Be in Cu at about 300°C) and 2.7 wt% Be (the maximum solubility of Be in Cu at 866°C).

(b) The heat treatment procedure, of course, will depend on the composition chosen. First of all, the solution heat treatment must be carried out at a temperature within the α phase region, after which, the specimen is quenched to room temperature. Finally, the precipitation heat treatment is conducted at a temperature within the $\alpha + \gamma_2$ phase region.

For example, for a 1.5 wt% Be-98.5 wt% Cu alloy, the solution heat treating temperature must be between about 600°C and 900°C, while the precipitation heat treatment would be below 600°C, and probably above 300°C. Below 300°C, diffusion rates are low, and heat treatment times would be relatively long.

Please not that since there is a solid state phase transformation from γ_1 à γ_2 in this system, if composition 1.7 wt% Be or higher is selected and the precipitation temperature is above 620°C, depending on the annealing temperature, the final structure may contain remnants of γ_1.