Chapter 1: Structure

This chapter focuses on Metallurgical and Materials Engineering problems, with an emphasis on crystal structures, diffusion, fractography, metallography, and phase diagrams.

Structure Problems

Problem 1-1

The following stress strain curves are for various grades of steel as compared to iron:

What does the plot suggest about the elastic modulus, ultimate tensile strength and ductility of the materials tested?

A. Elastic modulus increases with alloying and/or heat treatment, ductility increases with alloying and/or heat treatment, UTS increases with alloying and/or heat treatment
B. Elastic modulus decreases with alloying and/or heat treatment, ductility increases with alloying and/or heat treatment, UTS decreases with alloying and heat treatment
C. Elastic modulus does not change with alloying and/or heat treatment, ductility decreases with alloying and/or heat treatment, UTS increases with alloying and/or heat treatment
D. Elastic modulus does not change with alloying and/or heat treatment, ductility does not change with alloying and/or heat treatment, UTS increases with alloying and/or heat treatment
Structure Solutions

Solution 1-1

The modulus of elasticity is a material’s ability to resist elastic deformation. At the atomic level, this can be explained by the development of interatomic forces based on the distance between atoms. The distance between atoms (r) increases due to elastic strain, stretching the interatomic bonds causing an increase in interatomic forces. E-modulus is proportional to the slope of the interatomic force vs. separation curve \(E \propto dF/dr\). Because alloying or heat treatments do not change the atomic bonding of the material, modulus does not change.

The addition of alloying elements can lead to substitutional or interstitial solid solutions, with no change in the host material’s crystal structure. The alloying elements can strain the lattice and pin dislocations, making plastic deformation more difficult, which leads to increasing yield strength and ultimate tensile strength.

Heat treatments for steel create various microstructures that have a direct correlation with yield strength and ultimate tensile strength. A quenched and tempered steel will typically form tempered martensite, a highly desirable microstructure with enhanced toughness and ductility.

The answer is (C).

Solution 1-2

Determine the compositions of phases \(\alpha\) and \(\beta\) from the plot:

\[ C_\alpha : 5\% \text{ Sn}, 95\% \text{ Pb} \]
\[ C_\beta : 99\% \text{ Sn}, 1\% \text{ Pb} \]
\[ C_0 : 30\% \text{ Sn}, 70\% \text{ Pb} \]

Use the tie line equation to determine proportion of each phase:

\[ W_\alpha = \frac{C_\beta - C_0}{C_\beta - C_\alpha} \]
\[ W_\alpha = \frac{99\% - 30\%}{99\% - 5\%} \]
\[ W_\alpha = 73.4\% \]

\[ W_\beta = \frac{C_0 - C_\alpha}{C_\beta - C_\alpha} \]
\[ W_\beta = \frac{30\% - 5\%}{99\% - 5\%} \]
\[ W_\beta = 26.6\% \]

The answer is (D).
Chapter 3: Processing

This chapter focuses on processing aspects of materials. It covers problems based on casting, elastic/plastic deformation, coatings, heat transfer, heat treatment, joining methods, powder processing, and toughening.

Processing Problems

Problem 3-1

Cast iron sewer pipe is susceptible to pitting corrosion and graphitization when corrosive species stagnate on the inner diameter surface of the pipe for extended periods of time. A schematic cross section of the inner and outer diameter cast surfaces of the pipe are shown below. What features of the microstructures should be avoided during the casting process and what can be done to inhibit formation of this microstructure?

A. Gray iron is brittle and forms under rapid cooling rates. The addition of silicon acts as a graphite stabilizer and slower cooling rates aid in the formation of white iron microstructures.
B. Nodular iron is brittle and forms under rapid cooling rates. The addition of phosphorus acts as a graphite stabilizer, and slower cooling rates aid in the formation of gray iron microstructures.
C. White iron is brittle and forms under rapid cooling rates. The addition of silicon acts as a graphite stabilizer, and slower cooling rates aid in the formation of gray iron microstructures.

Problem 3-2

A mill product, an aluminum alloy strip, is cold rolled in a two-high mill with rollers of radii equal to 12 inches. The strip width is 8 inches, and the final strip thickness is 0.2 inches. The inlet velocity of the strip is 30% of the outlet velocity. What is the specific rolling pressure if a rolling load of 1200 kip is used?

A. 60.2 ksi  
B. 71.5 ksi  
C. 80.3 ksi  
D. 92.4 ksi
Processing Solutions

Solution 3-1

Examination of the microstructure near the inner diameter of the cast iron pipe reveals dark graphite features within a matrix containing ferrite/pearlite. Examination of the microstructure near the outer diameter surface reveals a dendritic microstructure containing cementite. These cast structures are consistent with slow and rapid cooling rates. Graphite formation is stabilized in cast iron with the addition of silicon.

The answer is (C).

Solution 3-2

The following is the relationship between initial and final thickness, and initial and final strip velocity during cold rolling:

\[
\frac{V_0}{V_f} = 0.30 = \frac{h_f}{h_0}
\]

Solving for the initial thickness:

\[
h_0 = \frac{0.2 \text{ in}}{0.30} = 0.6667 \text{ in}
\]

Determine the change in thickness:

\[
\Delta h = h_0 - h_f
\]

\[
= 0.6667 \text{ in} - 0.3 \text{ in}
\]

\[
= 0.3667 \text{ in}
\]

Use the equation for the projected length of the contact arc:

\[
L_p = \sqrt{R\Delta h}
\]

\[
= \sqrt{(12 \text{ in})(0.3667 \text{ in})}
\]

\[
= 2.097 \text{ in}
\]

Lastly, use the equation for specific rolling pressure:

\[
P = \frac{F}{wL_p}
\]

\[
= \frac{1200000 \text{ lbf}}{(8 \text{ in})(2.097 \text{ in})}
\]

\[
= 71,509.69 \text{ psi} (71.5 \text{ ksi})
\]

The answer is (B).

Solution 3-3

The image shows forging/flow lines, which are indications of microstructure directionality that is caused by the forging process. These features are not considered a forging defect, but do result in decreased ductility and fatigue properties in the direction transverse to the flow, and lead to second phases and inclusions orientating themselves parallel to the direction of forging deformation.

The answer is (A).