

11.2 (a) Ferrous alloys are used extensively because:

- (1) Iron ores exist in abundant quantities.
- (2) Economical extraction, refining, and fabrication techniques are available.
- (3) The alloys may be tailored to have a wide range of properties.

(b) Disadvantages of ferrous alloys are:

- (1) They are susceptible to corrosion.
- (2) They have a relatively high density.
- (3) They have relatively low electrical conductivities.

11.3 The alloying elements in tool steels (e.g., Cr, V, W, and Mo) combine with the carbon to form very hard and wear-resistant carbide compounds.

11.5 Gray iron is weak and brittle in tension because the tips of the graphite flakes act as points of stress concentration.

11.6 This question asks us to compare various aspects of gray and malleable cast irons.

(a) With respect to composition and heat treatment:

Gray iron--2.5 to 4.0 wt% C and 1.0 to 3.0 wt% Si. For most gray irons there is no heat treatment after solidification.

Malleable iron--2.5 to 4.0 wt% C and less than 1.0 wt% Si. White iron is heated in a nonoxidizing atmosphere and at a temperature between 800 and 900°C for an extended time period.

(b) With respect to microstructure:

Gray iron--Graphite flakes are embedded in a ferrite or pearlite matrix.

Malleable iron--Graphite clusters are embedded in a ferrite or pearlite matrix.

(c) With respect to mechanical characteristics:

Gray iron--Relatively weak and brittle in tension; good capacity for damping vibrations.

Malleable iron--Moderate strength and ductility.

11.7 This question asks us to compare white and nodular cast irons.

(a) With regard to composition and heat treatment:

White iron--2.5 to 4.0 wt% C and less than 1.0 wt% Si. No heat treatment; however, cooling is rapid during solidification.

Nodular cast iron--2.5 to 4.0 wt% C, 1.0 to 3.0 wt% Si, and a small amount of Mg or Ce. A heat treatment at about 700°C may be necessary to produce a ferritic matrix.

(b) With regard to microstructure:

White iron--There are regions of cementite interspersed within pearlite.

Nodular cast iron--Nodules of graphite are embedded in a ferrite or pearlite matrix.

(c) With respect to mechanical characteristics:

White iron--Extremely hard and brittle.

Nodular cast iron--Moderate strength and ductility.

11.11 The chief difference between heat-treatable and nonheat-treatable alloys is that heat-treatable alloys may be strengthened by a heat treatment wherein a precipitate phase is formed (precipitation hardening) or a martensitic transformation occurs. Nonheat-treatable alloys are not amenable to strengthening by such treatments.

11.12 This question asks us for the distinctive features, limitations, and applications of several alloy groups.

Titanium Alloys

Distinctive features: relatively low density, high melting temperatures, and high strengths are possible.

Limitation: because of chemical reactivity with other materials at elevated temperatures, these alloys are expensive to refine.

Applications: aircraft structures, space vehicles, and in chemical and petroleum industries.

Refractory Metals

Distinctive features: extremely high melting temperatures; large elastic moduli, hardnesses, and strengths.

Limitation: some experience rapid oxidation at elevated temperatures.

Applications: extrusion dies, structural parts in space vehicles, incandescent light filaments, x-ray tubes, and welding electrodes.

Superalloys

Distinctive features: able to withstand high temperatures and oxidizing atmospheres for long time periods.

Applications: aircraft turbines, nuclear reactors, and petrochemical equipment.

Noble Metals

Distinctive features: highly resistant to oxidation, especially at elevated temperatures; soft and ductile.

Limitation: expensive.

Applications: jewelry, dental restoration materials, coins, catalysts, and thermocouples.

Forming Operations

11.13 The advantages of cold working are:

- (1) A high quality surface finish.
- (2) The mechanical properties may be varied.
- (3) Close dimensional tolerances.

The disadvantages of cold working are:

- (1) High deformation energy requirements.
- (2) Large deformations must be accomplished in steps, which may be expensive.
- (3) A loss of ductility.

The advantages of hot working are:

- (1) Large deformations are possible, which may be repeated.
- (2) Deformation energy requirements are relatively low.

The disadvantages of hot working are:

- (1) A poor surface finish.
- (2) A variety of mechanical properties is not possible.

11.18 If a steel weld is cooled very rapidly, martensite may form, which is very brittle. In some situations, cracks may form in the weld region as it cools.

Annealing Processes

11.19 Full annealing--Heat to about 50°C above the A_3 line, Figure 11.10 (if the concentration of carbon is less than the eutectoid) or above the A_1 line (if the concentration of carbon is greater than the eutectoid) until the alloy comes to equilibrium; then furnace cool to room temperature. The final microstructure is coarse pearlite.

Normalizing--Heat to at least 55°C above the A_3 line Figure 11.10 (if the concentration of carbon is less than the eutectoid) or above the A_{cm} line (if the concentration of carbon is greater than the eutectoid) until the alloy completely transforms to austenite, then cool in air. The final microstructure is fine pearlite.

Quenching--Heat to a temperature within the austenite phase region and allow the specimen to fully austenitize, then quench to room temperature in oil or water. The final microstructure is martensite.

Tempering--Heat a quenched (martensitic) specimen, to a temperature between 450 and 650°C, for the time necessary to achieve the desired hardness. The final microstructure is tempered martensite.

Heat Treatment of Steels

11.24 Hardness is a measure of a material's resistance to localized surface deformation, whereas hardenability is a measure of the depth to which a ferrous alloy may be hardened by the formation of martensite. Hardenability is determined from hardness tests.

11.25 The presence of alloying elements (other than carbon) causes a much more gradual decrease in hardness with position from the quenched end for a hardenability curve. The reason for this effect is that alloying elements retard the formation of pearlitic and bainitic structures which are not as hard as martensite.

Precipitation Hardening

11.30 This problem asks us to compare various aspects of precipitation hardening, and the quenching and tempering of steel.

(a) With regard to the total heat treatment procedure, the steps for the *hardening of steel* are as follows:

- (1) Austenitize above the upper critical temperature.
- (2) Quench to a relatively low temperature.
- (3) Temper at a temperature below the eutectoid.
- (4) Cool to room temperature.

With regard to *precipitation hardening*, the steps are as follows:

- (1) Solution heat treat by heating into the solid solution phase region.
- (2) Quench to a relatively low temperature.
- (3) Precipitation harden by heating to a temperature that is within the solid two-phase region.
- (4) Cool to room temperature.

(b) For the *hardening of steel*, the microstructures that form at the various heat treating stages in part (a) are:

- (1) Austenite
- (2) Martensite
- (3) Tempered martensite
- (4) Tempered martensite

For *precipitation hardening*, the microstructures that form at the various heat treating stages in part (a) are:

- (1) Single phase
- (2) Single phase--supersaturated
- (3) Small plate-like particles of a new phase within a matrix of the original phase.
- (4) Same as (3)

(c) For the *hardening of steel*, the mechanical characteristics for the various steps in part (a) are as follows:

- (1) Not important
- (2) The steel becomes hard and brittle upon quenching.
- (3) During tempering, the alloy softens slightly and becomes more ductile.
- (4) No significant changes upon cooling to or maintaining at room temperature.

For *precipitation hardening*, the mechanical characteristics for the various steps in part (a) are as follows:

- (1) Not important
- (2) The alloy is relatively soft.
- (3) The alloy hardens with increasing time (initially), and becomes more brittle; it may soften

with overaging.

- (4) The alloy may continue to harden or overage at room temperature.

11.31 For precipitation hardening, natural aging is allowing the precipitation process to occur at the ambient temperature; artificial aging is carried out at an elevated temperature.

DESIGN PROBLEMS**Ferrous Alloys****Nonferrous Alloys**

11.D1 This problem calls for us to select, from a list of alloys, the best alloy for each of several applications and then to justify each choice.

(a) Gray cast iron would be the best choice for an engine block because it is relatively easy to cast, is wear resistant, has good vibration damping characteristics, and is relatively inexpensive.

(b) Stainless steel would be the best choice for a heat exchanger to condense steam because it is corrosion resistant to the steam and condensate.

(c) Titanium alloys are the best choice for high-speed aircraft jet engine turbofan blades because they are light weight, strong, and easily fabricated very resistant to corrosion. However, one drawback is their cost.

(d) A tool steel would be the best choice for a drill bit because it is very hard retains its hardness at high temperature and is wear resistant, and, thus, will retain a sharp cutting edge.

(e) For a cryogenic (low-temperature) container, an aluminum alloy would be the best choice; aluminum alloys have an FCC crystal structure, and therefore, are ductile at very low temperatures.

(f) As a pyrotechnic in flares and fireworks, magnesium is the best choice because it ignites easily and burns readily in air with a very bright flame.

(g) Platinum is the best choice for high-temperature furnace elements to be used in oxidizing atmospheres because it is very ductile, has a relatively very high melting temperature, and is highly resistant to oxidation.

11.D15 We are asked to specify a practical heat treatment for a 2014 aluminum alloy that will produce a minimum yield strength of 345 MPa (50,000 psi), and a minimum ductility of 12%EL. From Figure 11.27(a), the following heat treating temperatures and time ranges are possible to give the required yield strength.

<u>Temperature (°C)</u>	<u>Time Range (h)</u>
260	not possible
204	0.3-15
149	10-700
121	300-?

With regard to temperatures and times to give the desired ductility [Figure 11.27(b)]:

<u>Temperature (°C)</u>	<u>Time Range (h)</u>
260	<0.02, >10
204	<0.4, >350
149	<20
121	<1000

From these tabulations, the following may be concluded:

It is not possible to heat treat this alloy at 260°C so as to produce the desired set of properties—attainment of a yield strength of 345 MPa is not possible at this temperature.

At 204°C, the heat treating time would need to be about 0.4 h, which is practical.

At 149°C, the time range is between 10 and 20 h, which is a little on the long side.

Finally, at 121°C, the time range is unpractically long (300 to 1000 h).