There are two main kinds of steels: plain carbon steels and alloy steels.

Plain carbon steels are divided into three main groups: low-carbon steel, also known as mild steel; medium-carbon steel; and high-carbon steel.

There are many kinds of alloy steels. The properties of each depend on the other elements (usually metals) that are added to the steel.

Table 6-1

<table>
<thead>
<tr>
<th>Percent by weight of carbon in steel</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Carbon:</td>
<td></td>
</tr>
<tr>
<td>0.05-0.20</td>
<td>Automobile bodies, buildings, pipes, chains, rivets, screws, nails.</td>
</tr>
<tr>
<td>0.20-0.30</td>
<td>Gears, shafts, bolts, forgings, bridges, buildings.</td>
</tr>
<tr>
<td>Medium-Carbon:</td>
<td></td>
</tr>
<tr>
<td>0.30-0.40</td>
<td>Connecting rods, crank pins, axles, drop forgings.</td>
</tr>
<tr>
<td>0.40-0.50</td>
<td>Car axles, crankshafts, rails, boilers, auger bits, screwdrivers.</td>
</tr>
<tr>
<td>0.50-0.60</td>
<td>Hammers, sledges.</td>
</tr>
<tr>
<td>High-Carbon:</td>
<td></td>
</tr>
<tr>
<td>0.60-0.70</td>
<td>Stamping and pressing dies, drop-forging dies, drop forgings, screwdrivers, blacksmiths' hammers, table knives, setscrews.</td>
</tr>
<tr>
<td>0.70-0.80</td>
<td>Punches, cold chisels, hammers, sledges, shear blades, table knives, drop-forging dies, anvil faces, wrenches, vise jaws, band saws, crowbars, lathe centers, rivet sets.</td>
</tr>
<tr>
<td>0.80-0.90</td>
<td>Punches, rivet sets, large taps, threading dies, drop-forging dies, shear blades, table knives, saws, hammers, cold chisels, woodworking chisels, rock drills, axes, springs.</td>
</tr>
<tr>
<td>0.90-1.00</td>
<td>Taps, small punches, threading dies, needles, knives, springs, machinists' hammers, screwdrivers, drills, milling cutters, axes, reamers, rock drills, chisels, lathe centers, hacksaw blades.</td>
</tr>
<tr>
<td>1.00-1.10</td>
<td>Axes, chisels, small taps, hand reamers, lathe centers, mandrels, threading dies, milling cutters, springs, turning and planing tools, knives, drills.</td>
</tr>
<tr>
<td>1.10-1.20</td>
<td>Milling cutters, reamers, woodworking tools, saws, knives, ball bearings, cold cutting dies, threading dies, taps, twist drills, pipe cutters, lathe centers, hachets, turning and planing tools.</td>
</tr>
<tr>
<td>1.20-1.30</td>
<td>Turning and planing tools, twist drills, scythes, files, circular cutters, engravers' tools, surgical cutlery, saws for cutting metals, tools for turning brass and wood, reamers.</td>
</tr>
<tr>
<td>1.30-1.40</td>
<td>Small twist drills, razors, small engravers' tools, surgical instruments, knives, boring tools, wire drawing dies, tools for turning hard metals, files, woodworking chisels.</td>
</tr>
<tr>
<td>1.40-1.50</td>
<td>Razors, saws for cutting steel, wire drawing dies, fine cutters.</td>
</tr>
</tbody>
</table>
carbon steel is used for forge work, rivets, chains, and machine parts that do not need great strength. It is also used for almost every product that was once made of wrought iron.

Some low-carbon steel is **cold-rolled** between highly polished rollers under great pressure. This improves its tensile strength, and gives it a very smooth finish and exact size. It is then called **cold-rolled steel**.

### 6-2 Medium-Carbon Steel

Medium-carbon steel has more carbon and is stronger than low-carbon steel. It is also more difficult to bend, weld, and cut than low-carbon steel. It contains .30% to .60% carbon. Medium-carbon steel is used for bolts, shafts, car axles, rails, and other parts or tools that require strong metal. (See Table 6-1.)

Medium-carbon steels are frequently hardened and **tempered** by heat treatment. These steels can be hardened to a Rockwell-C hardness of 40 (medium hard) to 60 (very hard), depending on the carbon content and the thickness of the material. Unit 94 describes the Rockwell hardness test.

### 6-3 High-Carbon Steel

High-carbon steel, also known as **carbon tool steel**, contains between .60% and 1.50% carbon. The best grades of this steel are made in electric furnaces. High-carbon steel is called tool steel because it is used to make such tools as drills, taps, dies, reamers, files, cold chisels, crowbars, and hammers. (See Table 6-1.) It is hard to bend, weld, and cut.

High-carbon steel becomes very hard and brittle when it is hardened. The more carbon a steel contains, up to 0.80%, the harder it can be made. Hardness of Rockwell 60-66 can be attained.

High-carbon steel is rolled to the desired shape and is often ground to provide a smooth finish. Round bars that are accurately ground to standard drill sizes are called **drill rod**. Drill rod is used for making such tools as drills, reamers, taps, and punches. It is also used to make **dowel pins**. Dowel pins are used in die making to keep metal parts accurately aligned with each other.

- **Free-machining carbon steels** are especially made to have high machinability. **Resulfurized carbon steels**, which have sulfur added in amounts from .08% to .33%, have much better machinability than plain carbon steels. The resulfurized steel designated AISI 1112 is given a machinability rating of 100%. Other steels are rated in comparison with AISI 1112 steel, as described in Section 2-3. For example, AISI 1012, a plain low-carbon steel, has a machinability rating of only 53%.

  Lead is sometimes added to further improve the machinability of resulfurized steels. The percentage of lead added is small. Only about one third of a pound of lead for each hundred pounds of steel [15 grams per 45 kg] is used. Some leading free-machining steels have machinability ratings as high as 300%.

  A new free-machining steel alloy, DK1210, does not contain lead. It is capable of cutting speeds equalling or exceeding leaded steels and provides longer tool life. The alloy contains 0.10% bismuth and has a slightly higher sulfur content than the other free-machining steels.

  Free-machining steels are used in automatic lathes for the high-speed manufacture of cylindrical and threaded parts.

  Table 6-2 indicates some properties of several types of steel that are frequently used in industry and in metalworking classes.

### 6-4 Alloy Steels

- Alloy steels are made by combining steels with one or more other elements. These elements are usually metals. They are intentionally added to obtain properties that are not found in plain carbon steels. Alloying may increase the following properties:
Table 6-2

Physical Properties of Steels

<table>
<thead>
<tr>
<th>AISI no.</th>
<th>Condition of steel</th>
<th>Tensile strength [psi]</th>
<th>MPa</th>
<th>Brinell hardness*</th>
<th>Machinability rating [B 1112 = 100]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 1018</td>
<td>Hot-Rolled</td>
<td>69,000</td>
<td>475.7</td>
<td>143</td>
<td>52</td>
</tr>
<tr>
<td>C 1018</td>
<td>Cold-Drawn</td>
<td>82,000</td>
<td>565.4</td>
<td>163</td>
<td>65</td>
</tr>
<tr>
<td>B 1112</td>
<td>Cold-Drawn</td>
<td>82,500</td>
<td>568.8</td>
<td>170</td>
<td>100</td>
</tr>
<tr>
<td>B 1113</td>
<td>Cold-Drawn</td>
<td>83,500</td>
<td>575.7</td>
<td>170</td>
<td>130</td>
</tr>
<tr>
<td>Ledloy 375</td>
<td>Cold-Drawn</td>
<td>79,000</td>
<td>544.7</td>
<td>155</td>
<td>220</td>
</tr>
<tr>
<td>C 1045</td>
<td>Cold-Drawn</td>
<td>103,000</td>
<td>710.2</td>
<td>217</td>
<td>60</td>
</tr>
<tr>
<td>C 1095</td>
<td>Hot-Rolled</td>
<td>142,000</td>
<td>979.1</td>
<td>293</td>
<td></td>
</tr>
<tr>
<td>C 1095</td>
<td>Water-Quenched at 1450°F, [788°C] Tempered at 800°F, [427°C].</td>
<td>200,000</td>
<td>1379.0</td>
<td>388</td>
<td></td>
</tr>
</tbody>
</table>

*Brinell Hardness is a standard measure of hardness that works best on metals that are not extremely hard.
The steels measured here range from low to medium Brinell hardness.

1. Hardenability
2. Machinability
3. Strength through heat treatment
4. Strength as manufactured
5. Corrosion resistance
6. Wear resistance
7. Retention of hardness and strength at high temperatures.

The most important of the above properties are increased hardenability, corrosion resistance, and retention of hardness and strength at high temperatures. Most steel alloys must be heat-treated to develop their best properties.

There are three classes of alloy steels: constructional alloy steels, alloy tool steels, and special alloy steels.

**Constructional alloy steels.** These steels are used for such parts as shafts, gears, levers, bolts, springs, piston pins, and connecting rods. This group of alloys also includes steels used in the construction of bridges, auto frames, railroads, buildings, and ships. The constructional alloy steels have a relatively low alloy content as compared to alloy tool steels. Total alloy content of these steels ranges from 0.25% to about 6%.

**Alloy tool steels.** Alloy tool steels are used in making cutting and forming tools. They are used for high-quality drills, reamers, milling cutters, threading tools, punches, plastic molds, punch press tooling, and wrenches. Most alloy tool steels must be hardened in oil or air. Therefore, they are often referred to as oil-hardened or air-hardened tool steels. Generally, they harden more deeply than plain carbon tool steels and are more shock-resistant.

The total alloy content of alloy tool steels ranges from 0.25% to over 38%. There are hundreds of alloy tool steels. They are classified into different categories according to their basic properties. Each category has many grades. See Table 8-2.

**Special alloy steels.** Special alloy steels are designed for extreme service requirements. They include steels with very high heat, corrosion, or wear resistance. Included also are steels that get tougher and harder with use, such as those needed for power shovel teeth, tractor lugs, and rock crusher jaws.

**Effects of Allo ning Elements**

About 26 elements are used, alone or in combination, in making alloy steels. The following paragraphs describe how the most important alloying elements affect the properties of steel.

**Chromium, also known as chrome,** gives hardness to steel, and toughens it. It also
makes the steel’s grain finer and causes the steel to resist rust, stains, shocks, and scratches. Chromium steel is used for safes, rock crushers, and automobile bearings.

Chromium is the basis for **stainless steel**, which contains from 11% to 26% chromium. It has a lasting, bright, silvery gloss. Following is a list of some important uses for stainless steel:

- sinks
- tableware
- pots and pans
- cutting tools
- plates for false teeth
- dental tools
- ball bearings
- fine measuring tools
- molds
- automobile parts
- valves for airplane engines

**Cobalt** is an important metal used in making cutting tool alloys. (These alloys include high-speed steels, cast alloys, and cemented carbides.) The outstanding property of cobalt is its ability to improve the hardness of cutting tools when they are hot or even red-hot. Such properties are called the **hot-hardness** or **red-hardness** of cutting tools. Cutting tools with high cobalt content retain their hardness up to a dull red heat. Cobalt also improves wear resistance. Cobalt content in high-speed steels ranges from 5% to 12%. In cast alloys, it is used in amounts from 35% to 55%.

Cobalt is also alloyed with aluminum and nickel to make powerful **Alnico** permanent magnets.

**Manganese** is a hard, brittle, grayish-white metal. It purifies and adds strength and toughness to steel. Manganese steel remains hard even when cooled slowly. It is so very hard that it is difficult to cut, so it is usually **cast** into shape. **Wear** makes the surface harder. Manganese steel can stand hard wear, strain, hammering, and shocks. It is used for the jaws of rock and ore crushers, steam shovels, chains, gears, railway switches and crossings, and safes.

**Molybdenum** is called “Molly” for short in steel mills. A silvery white metal, it adds strength and hardness to steel, and allows it to stand heat and shocks. Molybdenum steel is used for automobile parts, high-grade machinery, wire as fine as 0.0004” [0.01 mm] in diameter, ball bearings, and roller bearings.

**Nickel** adds strength and toughness to steel. Nickel steel does not rust easily and is very strong and hard. It is also **elastic**; that is, it can stand vibration, shocks, jolts, and wear by bouncing back to its original shape. It is used for wire cables, shafts, steel rails, automobile and railroad car axles, and **armor plate**. Nickel is also used with chromium to make **stainless steel**.

**Tungsten** is a rare, heavy, white metal that has a higher melting point than any other metal. Tungsten adds hardness to steel. It gives steel a fine grain, and allows steel to withstand heat. Tungsten is used as an alloying element in tool steels, high-speed steels, and in cemented carbide. It is also used in armor plate.

**Vanadium** is a pale, silver-gray metal. It is brittle and resists corrosion. Vanadium gives steel a fine grain, as well as toughness and strength. Vanadium steel can withstand great shocks. It is used for springs, automobile axles and gears, and other parts that vibrate when in use.

**Chromium-vanadium steel** is hard and has great **tensile strength**. It can be bent double while cold and is easy to cut. Chromium-vanadium steel is used for automobile parts such as springs, gears, steering knuckles, frames, axles, connecting rods, and other parts which must be strong and tough but not brittle.

### High-Speed Steel (HSS)

High-speed steel, also known as **high-speed tool steel**, is another type of alloy steel. Its carbon content may range from about 0.70% to 1.50%. Several different grades are available. It generally contains one or more metals such as **chromium**, **vanadium**, **molybdenum**, **tungsten**, and **cobalt**. The first four of these elements are carbide formers. They combine with carbon to form carbides such as chromium carbide and vanadium carbide. These carbides are very hard and wear-resistant; therefore, they make good cutting tools.

Cobalt is not a carbide former, but it increases the **red-hardness** of the cutting tool. Thus, the tool retains its hardness at high temperatures. High-speed steel cutting tools retain their hardness without significant soft-
enewing at temperatures up to about 1100°F [593°C]. This temperature is indicated by a
dull, red heat. On the other hand, plain-carbon
tool-steel cutting tools start to soften
significantly at temperatures above 450°F
[232°C].

High-speed steel is made in an electric fur-
nace. It is used for cutting tools such as drills,
reamers, countersinks, lathe tool bits, and
milling cutters. It is called high-speed steel be-
cause cutting tools made of this material can
be operated at speeds twice as fast as those for
tools made of plain carbon tool steel. High-
speed steels cost two to four times as much as
carbon tool steels.

---

**Words to Know**

<table>
<thead>
<tr>
<th>alloy steels</th>
<th>free-machining</th>
<th>low-carbon steel</th>
<th>nickel</th>
</tr>
</thead>
<tbody>
<tr>
<td>chromium</td>
<td>carbon steel</td>
<td>manganese</td>
<td>stainless steel</td>
</tr>
<tr>
<td>cobalt</td>
<td>hardenability</td>
<td>medium-carbon</td>
<td>tungsten</td>
</tr>
<tr>
<td>dowel pins</td>
<td>high-carbon steel</td>
<td>steel</td>
<td>vanadium</td>
</tr>
<tr>
<td>drill rod</td>
<td>high-speed steel</td>
<td>molybdenum</td>
<td></td>
</tr>
</tbody>
</table>

**Review Questions**

1. List the three groups of plain carbon steel together with their range of carbon contents.
2. Name several uses for each of the three groups of plain carbon steels.
3. What is done to steel to make it free-machining?
4. What is an alloy steel?
5. Why is steel alloyed?
6. Name the three classes of alloy steels and give several uses for each.
7. List each of the alloying elements discussed, together with its principal benefit when alloyed with steel.
8. What is high-speed steel? What is it used for? Why is it called high-speed steel?