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Steel Production and Refining

Future development will be towards increased recycling, waste minimization, decreased liquid waste, elimination of noxious gases, and decreased vapor and dust emissions. The problem of CO₂ production is not simply solved as no economic reductant, other than carbon, is available at this time.

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A. W. Cramb

Steels: Classifications

The beginning point for the classification of steels and iron is the iron-carbon phase diagram (see *Ferrous Alloys: Overview and Phase Equilibria in Fe-C, Fe-X, Fe-C-X and Fe-C-Xi*). All Fe-C alloys containing less than about 2.06 wt.% carbon would pass through the austenite field when cooled slowly from the liquid to room temperature. All binary Fe-C alloys containing <2.06 wt.% carbon are classed as steels. All binary Fe-C alloys containing >2.06 wt.% carbon are termed *cast irons*. These distinctions are roughly maintained even when the alloys contain large amounts of alloying elements.

Cast irons typically have carbon levels of about 2–4 wt.% carbon. There are many types of cast irons. Most are the so-called graphitic cast irons but there are other high-alloy cast irons designed for wear resistance, corrosion resistance, and heat resistance. The graphitic cast irons (see *Cast Irons*) are alloys with the above approximate ranges of carbon content but which also contain 0.5–3.0 wt.% silicon. The purpose of the silicon is to promote the formation of graphite rather than iron carbide (cementite) on solidification or during heat treatment. Depending on the exact composition, cooling rate on solidification, and subsequent heat treatment these materials consist of particles of either cementite or graphite embedded in a steel matrix which can be entirely ferritic, ferritic-pearlitic, martensitic, or austenitic. In white cast irons the material consists of cementite in a steel matrix. The other types of cast irons consist of particles of graphite in a steel matrix. There are four different types of graphitic cast irons, gray, ductile, malleable, and compacted and these grades differ primarily in the shape of the graphite particles. In the four types the graphite shapes are plates, spheres, popcorn shaped, and rods, respectively. The strengths of each of these types of cast irons can be varied by changing the nature of the steel matrix.

For the purpose of this article steels will be regarded as all ferrous-based alloys with carbon levels in the range of 0–2 wt.%. The approach taken here is similar to that adopted by Leslie where almost all of the steels described here are discussed in greater detail (Leslie 1981).

The most widely produced steel product is sheet (see *Sheet Steel: Low Carbon*). These materials are ferrite with low carbon contents and are often used in

applications requiring the sheet to be formed into complex shapes, such as auto bodies. High formability is achieved in these materials by reducing the interstitials, carbon and nitrogen, to very low levels and by developing appropriate textures through thermo-mechanical processing and control of inclusion characteristics (see *Nucleation of Ferrous Solid-Solid Phase Transformations at Inclusions*). Steel sheet can be coated in a variety of ways to provide corrosion protection and for decorative purposes (see *Sheet Steel: Coated*). These coatings reduce formability.

By adding carbon pearlite can be introduced (see *Pearlite*) into steels slowly cooled from the austenitizing temperature. When steels having less than the eutectoid carbon content are slowly cooled from the austenitizing temperature pro-eutectoid ferrite (see *Proeutectoid Ferrite*) is formed as the steel is cooled to the eutectoid temperature. Once the steel is cooled below the eutectoid temperature the remaining austenite, now of the eutectoid carbon content, transforms to pearlite, which consists of alternating layers of cementite and ferrite. The amount of pearlite in the structure increases with increasing carbon content. The strength of the steel increases with the amount of pearlite and the strength of pearlite can be increased by decreasing the spacing between the alternating sheets of ferrite and cementite. Low carbon sheet steels which contain no pearlite are one extreme of the ferritic-pearlitic steel spectrum and steels of the eutectoid carbon content which are entirely pearlite when slowly cooled represent the other extreme of the ferritic-pearlitic steel spectrum. Steels of the eutectoid carbon content (see *Steels: Near Eutectoid*) are commonly used for railroad tracks and wheels.

When an Fe-C alloy is cooled (quenched) sufficiently rapidly from the austenitizing temperature the austenite will not transform to a combination of pro-eutectoid ferrite and pearlite, or to bainite (see *Bainite*). Instead the alloy will transform to martensite, a body-centered-tetragonal phase, in which the carbon is in solid solution (see *Martensite*). The carbon in solid solution in the martensite is much more effective in strengthening martensite than is the pearlite in strengthening ferritic-pearlitic steels. For this reason martensitic steels are used to achieve high strength levels. However, to achieve a martensitic structure one must cool the material sufficiently rapidly to avoid the formation of pro-eutectoid ferrite, pearlite, and bainite. Alloying additions can be used to delay the start of the decomposition of austenite to pro-eutectoid ferrite, pearlite, and bainite, and such alloying is said to increase the hardenability of the steel. When the hardenability is increased one can use slower quench rates to achieve a martensitic structure and achieve a martensitic structure in pieces of larger section size. Low alloy steels which were developed to be used primarily as martensitic steels are referred to as *heat-treated steels*. A primary concern in these steels is their hardenability. These steels are never used in their as-

quenched condition but are tempered. Tempering is the heating of a martensitic steel at a temperature below that at which austenite forms (see *Tempering of Martensite*). Tempering results in softening of the steel due to precipitation of the carbon as cementite and the coarsening of the cementite particles. Steels used for bearings (see *Bearing Steels*) are typically low alloy quenched and tempered steels. Krauss (1980) discusses the effects of composition and heat treatment on the microstructures and mechanical properties of low alloy steels.

Ferritic-pearlitic steels have very low strength when they are purely ferritic and their toughnesses drop rapidly as the carbon content and the amount of pearlite are increased. While the martensitic quenched and tempered low alloy steels have much better toughnesses (see *Martensite before and after Tempering, Deformation and Fracture of*) at higher strength levels than the ferritic-pearlitic steels, the quenched and tempered martensitic structure is difficult to achieve in many product forms. Costs are also associated with the heat treatment involved in obtaining the martensitic quenched and tempered microstructure. High-strength low-alloy (HSLA) steels are a class of steels developed to achieve properties superior to those of the ferritic-pearlitic steel and comparable to those of low alloy quenched and tempered martensitic steels. HSLA steels are designed to achieve their desired mechanical properties by the development of microstructures through controlled thermomechanical processing (TMP) and the steel is produced in its final form by a continuous hot deformation process, rolling, or forging, which comprise the TMP. Most HSLA steels are microalloyed with small additions (0.1 wt.%) of niobium, vanadium, and titanium which control microstructural evolution during TMP through the formation of carbonitride precipitates.

The above classes of steel have a low alloy content. Most other steels have higher alloy content and these steels were developed to achieve certain properties, often for particular applications.

The most widely used of the alloy steels are the stainless steels. These are steels with high chromium content, a minimum of about 11 wt.%. The chromium forms an oxide on the surface of the steel which is adherent and slows further oxidation or corrosion of the alloy. There are many types of stainless steels. They can be roughly distinguished on the basis of microstructure. The austenitic stainless steels (see *Austenitic Stainless Steels*) are low carbon stainless steels which are austenitic at room temperature and they normally contain about 18 wt.% chromium and about 8 wt.% nickel and/or manganese to stabilize the austenite. The austenitic stainless steels are used in applications requiring corrosion resistance and at elevated temperatures when both oxidation and creep resistance are required. The martensitic stainless steels (see *Stainless Steels: Martensitic*) are quenched and tempered steels and there are two classes of this type of

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