Carbon Steel

Carbon steel, also called plain carbon steel, is a malleable, iron-based metal containing carbon, small amounts of manganese, and other elements that are inherently present. Steels can either be cast to shape or wrought into various mill forms from which finished parts are formed, machined, forged, stamped, or otherwise shaped.

Cast steels are poured to near-final shape in sand molds. The castings are then heat treated to achieve specified properties and machined to required dimensions.

Wrought steel undergoes two operations. First, it is either poured into ingots or strand cast. Then, the metal is reheated and hot rolled into the finished, wrought form. Hot-rolled steel is characterized by a scaled surface and a decarburized skin. Hot-rolled bars may be subsequently finished in a two-part process. First, acid pickling or shot blasting removes scale. Then, cold drawing through a die and restraightening improves surface properties and strength. Hot-rolled steel may also be cold finished by metal-removal processes such as turning or grinding. Wrought steel can be subsequently heat treated to improve machinability or to adjust mechanical properties.

Carbon steels may be specified by chemical composition, mechanical properties, method of deoxidation, or thermal treatment (and the resulting microstructure).

Composition: Wrought steels are most often specified by composition. No single element controls the characteristics of a steel; rather, the combined effects of several elements influence hardness, machinability, corrosion resistance, tensile strength, deoxidation of the solidifying metal, and microstructure of the solidified metal.

Effects of carbon, the principal hardening and strengthening element in steel, include increased hardness and strength and decreased weldability and ductility. For plain carbon steels, about 0.2 to 0.25% C provides the best machinability. Above and below this level, machinability is generally lower for hot-rolled steels.

Standard wrought-steel compositions (for both carbon and alloy steels) are designated by an AISI or SAE four-digit code, the last two digits of which indicate the nominal carbon content. The carbon-steel grades are:

- 10xx: Plain carbon
- 11xx: Resulfurized
- 12xz: Resulfurized and rephosphorized
- 15xx: Nonresulfurized, Mn over 1.0%

The letter "L" between the second and third digits indicates a leaded steel; "B" indicates a boron steel. Cast-carbon steels are usually specified by grade, such as A, B, or C. The A grade (also LCA, WCA, AN, AQ, etc.) contains 0.25% C and 0.70% Mn maximum. B-grade steels contain 0.30% C and 1.00% Mn, and the C-grade steels contain 0.25% C and 1.20% Mn. These carbon and manganese contents are designed to provide good strength, toughness, and weldability. Cast carbon steels are specified to ASTM A27, A216, A352, or A487.

Microalloying technology has created a new category of steels, positioned both in cost and in performance between carbon steels and the alloy grades. These in-between steels consist of conventional carbon steels to which minute quantities of alloying elements -- usually less than 0.5% -- are added in the steelmaking process to improve mechanical properties. Strength and hardness are increased significantly.

Any base-grade steel can be microalloyed, but the technique was first used in sheet steel a number of years ago. More recently, microalloying has been applied to bar products to eliminate the need for heat-treating operations after parts are forged. Automotive and truck applications include connecting rods, blower shafts, stabilizer bars, U-bolts, and universal joints. Other uses are sucker rods for oil wells and anchor bolts for the construction industry.

Mechanical properties: Cast and wrought products are often specified to meet distinct mechanical requirements in structural applications where forming and machining are not extensive. When steels are specified by mechanical properties only, the producer is free to adjust the analysis of the steel (within limits) to obtain the required properties. Properties may vary with cross section and part size.

Mechanical tests are usually specified under one of two conditions: mechanical test requirements and no chemical limits on any element, or mechanical test requirements and chemical limits on one or more elements, provided that such requirements are technologically compatible.

Method of deoxidation: Molten steel contains dissolved oxygen -- an important element in the steelmaking reaction. How this oxygen is removed or allowed to escape as the metal solidifies determines some of the properties of the steel. So in many cases, "method of deoxidation" is specified in addition to AISI and SAE chemical compositions.

For "killed" steels, elements such as aluminum and silicon may be added to combine chemically with the oxygen, removing most of it from the liquid steel. Killed steels are often specified for hot forging, carburizing, and other processes or applications where maximum uniformity is required. In sheet steel, aging is controlled by killing -- usually with aluminum. Steels intended for use in the as-cast condition are always killed. For this reason, steels for casting are always fully deoxidized.

On the other hand, for "rimmed" steels, oxygen (in the form of carbon monoxide) evolves briskly throughout the solidification process. The outer skin of rimmed steels is practically free from carbon and is very ductile. For these reasons, rimmed steels are often specified for cold-forming applications. Rimmed steels are often available in grades with less than 0.25% C and 0.60% Mn.

Segregation -- a nonuniform variation in internal characteristics and composition that results when various alloying elements redistribute themselves during solidification -- may be pronounced in rimmed steels. For this reason, they are usually not specified for hot forging or for applications requiring uniformity.

"Capped" and "semikilled" steels fall between the rimmed and killed steels in behavior, properties, and degree of oxidation and segregation. Capped steels, for example, are suited for certain cold-forming applications because they have a soft, ductile, surface skin, which is thinner than rimmed-steel skin. For other cold-forming applications, such as cold extrusion, killed steels are more suitable.

Microstructure: The microstructure of carbon and alloy steels in the as-rolled or as-cast condition generally consists of ferrite and pearlite. This basic structure can be altered significantly by various heat treatments or by rolling techniques. A spheroidized annealed structure would consist of spheroids of iron and alloy carbides dispersed in a ferrite matrix for low hardness and maximum ductility, as might be required for cold-forming operations. Quenching and tempering provide the optimum combination of mechanical properties and toughness obtainable from steel. Grain size can also be an important aspect of the microstructure. Toughness of fine-grained steels is generally greater than that of coarse-grained steels.

Free-machining steels: Several free-machining carbon steels are available as castings and as hot-rolled or cold-drawn bar stock and plate. Machinability in steels is improved in several ways, including:

- Addition of elements such as lead (the "leaded" steels such as 12L13 and 12L14), phosphorus and sulfur (the "rephosphorized, resulfurized" steels such as 1211, 1212, or 1213), sulfur (the "resulfurized only" steels such as 1117, 1118, or 1119), and tellerium, selenium, and bismuth (the "super" free-machining steels)
- Cold finishing
- Reducing the level of residual stress (usually by a stress-relieving heat treatment)
- Adjusting microstructure to optimize machinability

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