Carbon and Alloy Steels– SAE J411 OCT80

SAE Information Report
Last Revised October 1980

THIS IS A PREPRINT WHICH IS SUBJECT TO REVISIONS AND CORRECTIONS. THE FINAL VERSION WILL APPEAR IN THE 1982 EDITION OF THE SAE HANDBOOK.

SAE The Engineering Resource For Advancing Mobility

PREPRINT

Report of the Iron and Steel Technical Committee, approved February 1948, fifth revision October 1980.

1. Steel—Steel is a malleable alloy of iron and carbon which has been made molten in the process of manufacture and which contains approximately 0.05-2.0% carbon, as well as some manganese and sometimes other alloying elements.

1.1 Carbon Steel—Steel is considered to be carbon steel when no minimum content is specified or required for aluminum, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, or zirconium, or any other element added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40%; or when the maximum content specified for any of the following elements does not exceed the following percentage: manganese, 1.65%; silicon, 0.60%; copper, 0.60%. Boron may be added to killed fine grain carbon steel to improve hardenability.

In all carbon steels, small quantities of certain residual elements, such as copper, nickel, molybdenum, chromium, etc., are unavoidably retained from raw materials. Those elements are considered incidental. However, if any of these elements are considered detrimental for special applications, the maximum acceptable content of these incidental elements should be specified by the purchaser.

1.2 Alloy Steel—Steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65%; silicon, 0.60%; copper, 0.60%; or in which a definite range or definite minimum quantity for any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels: aluminum and chromium up to 3.99%; cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain a desired alloying effect.

2. Steelmaking Processes—These fall into two general groups, acid or basic, according to the character of the furnace lining. Thus, open hearth or electric processes may be either acid or basic. Basic oxygen is a relatively recent addition to the list of steelmaking processes and, as the name implies, is exclusively basic. The choice of an acid or basic furnace is usually determined mainly by the phosphorus in the available raw materials and the content of phosphorus permissible in the finished steel.

Phosphorus is an acid-forming element and, in its oxide form, will react with any suitable base to form a slag in the steelmaking furnace. In basic processes, the metallurgist and steelmaker take advantage of this chemical behavior by oxidizing the phosphorus with iron oxide, which yields up its oxygen to the phosphorus. This permits the iron to remain as part of the steelmaking bath, while the acid phosphoric oxide is separated by floating up into the molten basic lime slag. In acid processes, furnaces are generally lined with silica, which is acid in nature and will not tolerate the use of basic materials for fluxes. Since an acid slag has no affinity for impurities such as phosphorus, the steel cannot be dephosphorized by fluxing and the content of this element remains at the level contained in the raw material, or may be concentrated somewhat in the finished steel due to loss of other materials from the original metallic charge.

Most iron ores in the United States are of a phosphorus content suitable only for basic steelmaking processes; hence, all of the nation's wrought steel is so made. A small proportion is low enough in phosphorus that steel could be made from it by acid processes, although such steels invariably would have higher residual phosphorus levels than steels made in basic lined furnaces. The following are the principal steelmaking processes used in the United States with approximate percentage of total raw steel production in 1972.

Basic oxygen: 56.0%
Basic open hearth: 26.2%
Basic electric: 17.8%

2.1 Basic Open Hearth—Because of its flexibility to accommodate iron produced from available ores and basic fluxes for removal of objectionable elements such as phosphorus and sulfur, the basic open hearth, until recently, has been the most widely used steelmaking process. It is used to produce all SAE carbon and alloy steels, except compositions designated as electric furnace grades.

2.2 Basic Electric—The principal advantage of this process is optional control in the furnace permitting steel to be treated under oxidizing, reducing, or neutral slags, and pouring off and replacement of slags during the process. In this manner, and depending upon specified requirements, objectionable elements may be substantially reduced and a high degree of refinement obtained in the steel bath. Practically all grades of steel can be made by the basic electric furnace; and the process is used exclusively for producing SAE wrought stainless steels.

2.3 Basic Oxygen—Steelmaking capacity by this process was first introduced in the United States and Canada in 1954 and has been growing at a substantial rate. It is now the most popular method of steel production. The prime advantage of this process is the rate at which steel can be produced. The nature of the process is such that large quantities of molten iron must be readily available, since refining is accomplished by the exothermic reactions of high-purity oxygen with the various elements contained in the molten iron. In respect to its essential chemical composition and metallurgical characteristics, steel of a specified grade which has been made by the basic oxygen process is similar to basic open hearth steel of the same grade. The differences between these two processes are chiefly in the design of the furnace employed and in the relative extent to which high-purity oxygen is used as a refining agent.

2.4 Vacuum Degassing Process—The use of vacuum degassing in the United States has grown rapidly since the first production installation. It can be employed with any of the principal steelmaking processes and is adaptable to all grades of carbon and alloy steel. The advantages of this process lie in its ability to reduce substantially the steel's soluble gas content and minimize the formation of oxide-type inclusions.

One of the basic mechanisms involved in vacuum degassing is carbon deoxidation at pressures lower than atmospheric (generally under 10 mm Hg). This process removes a substantial portion of the oxygen, nearly all of the hydrogen, and some nitrogen. The reduction in oxygen content generally results in fewer nonmetallic inclusions with corresponding improvement in mechanical properties. The reduced hydrogen content provides steel with improved internal soundness and resistance to internal rupturing or "flaking."

This process is particularly adaptable to steels which are used in critical stress applications, such as large generator rotors, bearing and aircraft components, etc.

2.5 Strand Casting—This process involves the direct casting of steel from the ladle into slabs, blooms, or billets. In strand casting, a heat of steel is tapped into a ladle in the conventional manner. The liquid steel is then teemed into a tundish which acts as a reservoir to provide for a controlled casting rate. The steel flows from the tundish into the casting machine and rapid solidification begins in the open-ended molds. The partially solidified slab, bloom, or billet is continuously extracted from the mold. Solidification is completed by cooling the moving steel surface. Several strands may be cast simultaneously, depending upon the heat size and section size. A reduction in size may be carried out by hot working the product prior to cutting the strand into lengths. Chemical segregation is minimized, due to the rapid solidification rate of the strand cast product.

When two or more heats are cast without interruption, the process is called continuous strand casting.

3. Quality Classifications—Technically, quality, as the term relates to steel products, may be indicative of many conditions such as the degree of internal soundness, relative uniformity of composition, relative freedom from injurious surface imperfections, and finish. Steel quality also relates to general suitability for particular applications. Sheet steel surface requirements may be broadly identified as to the end use by the suffix E for exposed parts requiring a good painted surface, and suffix U for unexposed parts for which surface finish is unimportant.

Carbon steel may be obtained in a number of fundamental qualities which reflect various degrees of the quality conditions mentioned above. The quality designations for various products are listed in Table 1. Some of those qualities may be modified by such requirements as limited austenitic grain size, special discard, macroetch test, special hardenability, maximum incidental alloy elements, restricted chemical composition, and nonmetallic inclusions. In addition, several of the products have special qualities which are intended for specific end uses or fabricating practices, that is, scrapless nut quality, axle shaft quality, gun barrel, shell quality.

Alloy steels also may be obtained in special qualities, some of which are listed in Table 1. Superimposed upon some of these qualities may be such requirements as extensometer test, fracture test, impact test, macroetch test, nonmetallic inclusion tests, special hardenability test, and grain size test.

For complete descriptions of the qualities and supplementary requirements for carbon and alloy steels, reference should be made to the latest applicable AISI Steel Products Manual Section. Manual titles are listed at the end of this SAE Information Report.

4. Types of Steel—In most steelmaking processes, the primary reaction is the combination of carbon and oxygen to form a gas. If the oxygen available for

The ϕ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

this reaction is not removed prior to or during casting, the gaseous products continue to evolve during solidification. Proper control of the evolution of gas determines the type of steel.

4.1 **Killed steel** is a type of steel from which there may be only a slight evolution of gases during solidification of the metal. Killed steels have more uniform chemical composition and properties than the other types. However, there may be variations in composition, depending upon the steelmaking practices used. Alloy steels are of the killed type, while carbon steels may be killed or may be of the following types.

4.2 **Rimmed steels** have marked differences in chemical composition across the section. The typical structure of rimmed steel results from a marked gas evolution during solidification of the outer rim, caused by a reaction between the carbon in the solidifying metal and dissolved oxygen. The outer rim is lower in carbon, phosphorus, and sulfur than the average composition, whereas the inner portion, or core, is higher than the average in those elements. The technology of manufacturing rimmed steels limits the maximum contents of carbon and manganese and those maximum contents vary among producers. Rimmed steels do not retain any significant percentages of highly oxidizable elements, such as aluminum, silicon, or titanium.

Rimmed steel products, because of their chemical composition and their surface and other characteristics, may be used advantageously for the manufacture of finished articles involving cold bending, cold forming, deep drawing, and, in some cases, cold heading applications.

4.3 **Semikilled steels** have characteristics intermediate between those of killed and rimmed steels. During the solidification of semikilled steel, some gas is evolved and entrapped within the body of the ingot. This tends to compensate for the shrinkage which accompanies solidification.

4.4 **Capped steels** have characteristics which combine some features of rimmed and semikilled steels. After pouring, the rimming action is stopped after a brief interval by means of mechanical or chemical capping. The thin lower carbon rim has surface and forming properties comparable to those of rimmed steel, whereas the uniformity of composition and properties more nearly approaches that of semikilled steels. Capped steel products, because of their chemical composition, surface, and other characteristics, may be used to advantage when the material is to withstand cold bending, cold forming, or cold heading.

5. Commonly Specified Elements—The effect of a single commonly specified element on steelmaking practice and carbon and alloy steel properties is dependent upon the effect of other elements. These interrelations, frequently of a complex nature, should be considered when evaluating a change in specified composition. It should be noted also that as the number of elements specified increases, and as restrictive requirements increase, availability generally decreases, to the ultimate end that special heats may become a necessity and material must be ordered in heat lots.

5.1 **Carbon**—The amount of carbon required in the finished steel limits the type of steel that can be made. As the carbon content of rimmed steels increases, surface quality becomes impaired. Killed steels, by comparison, have poorer surfaces in the lower carbon grades. Carbon has a moderate tendency to segregate, and because of its major effect on properties, carbon segregation is frequently of more significant importance than the segregation of other elements. It is the principal hardening element in all steel. Tensile strength in the as-rolled condition increases as the carbon increases up to about 0.85% carbon. Ductility and weldability decrease with increasing carbon.

5.2 **Manganese** has a lesser tendency to segregate than any of the common elements. Steels above 0.60% manganese cannot be readily rimmed.

Manganese is beneficial to surface quality in all carbon ranges (with the exception of extremely low carbon rimmed steels) and is particularly beneficial in high sulfur steels. It contributes to strength and hardness, but to a lesser degree than does carbon, the amount of increase being dependent upon the carbon content. Increasing the manganese content decreases ductility and weldability, but to a lesser extent than does carbon. Manganese has a moder-

TABLE 1—FUNDAMENTAL QUALITY DESCRIPTION[a] OF CARBON AND ALLOY STEELS[b]

Carbon Steels			Alloy Steels
SEMIFINISHED FOR FORGING Forging Quality Special Hardenability Special Internal Soundness Nonmetallic Inclusion Requirement Special Surface CARBON STEEL STRUCTURAL SECTIONS Structural Quality CARBON STEEL PLATES Regular Quality Structural Quality Cold Drawing Quality Cold Pressing Quality Cold Flanging Quality Forging Quality Pressure Vessel Quality Marine Quality HOT ROLLED CARBON STEEL BARS Merchant Quality Special Quality Special Hardenability Special Internal Soundness Nonmetallic Inclusion Requirement Special Surface Scrapless Nut Quality Axle Shaft Quality Cold Extrusion Quality Cold Heading and Cold Forging Quality COLD FINISHED CARBON STEEL BARS Standard Quality Special Hardenability Special Internal Soundness Nonmetallic Inclusion Requirement Special Surface Cold Heading and Cold Forging Quality Cold Extrusion Quality	HOT ROLLED SHEETS Commercial Quality Drawng Quality Drawing Quality Special Killed Physical Quality COLD ROLLED SHEETS Commercial Quality Drawing Quality Drawing Quality Special Killed Physical Quality PORCELAIN ENAMELING SHEETS Commercial Quality Drawing Quality LONG TERNE SHEETS Commercial Quality Drawing Quality Drawing Quality Special Killed Physical Quality GALVANIZED SHEETS Commercial Quality Drawing Quality Drawing Quality Special Killed Physical Quality Lock Forming Quality ELECTROLYTIC ZINC COATED SHEETS Commercial Quality Drawing Quality Drawing Quality Special Killed Physical Quality HOT ROLLED STRIP Commercial Quality Drawing Quality Drawing Quality Special Killed Physical Quality COLD ROLLED STRIP Specific quality descriptions are not provided in cold rolled strip, since this product is largely produced for specific end use.	TIN MILL PRODUCTS Specific quality descriptions are not applicable to tin mill products. CARBON STEEL WIRE Industrial Quality Wire Cold Extrusion Wires Heading, Forging and Roll Threading Wires Mechanical Spring Wires Upholstery Spring Construction Wires Welding Wire CARBON STEEL FLAT WIRE Stitching Wire Stapling Wire CARBON STEEL PIPE STRUCTURAL TUBING LINE PIPE OIL COUNTRY TUBULAR GOODS STEEL SPECIALTY TUBULAR PRODUCTS Pressure Tubing Mechanical Tubing Aircraft Tubing HOT ROLLED CARBON STEEL WIRE RODS Industrial Quality Rods for Manufacture of Wire Intended for Electric Welded Chain Rods for Heading, Forging, and Roll Threading Wire Rods for Lock Washer Wire Rods for Scrapless Nut Wire Rods for Upholstery Spring Wire Rods for Welding Wire	ALLOY STEEL PLATES Regular Quality or Structural Quality Drawing Quality Pressure Vessel Quality Structural Quality Aircraft Quality Aircraft Physical Quality HOT ROLLED ALLOY STEEL BARS Regular Quality Aircraft Quality or Steel Subject to Magnetic Particle Inspection Axle Shaft Quality Bearing Quality Cold Heading Quality Special Cold Heading Quality Rifle Barrel Quality, Gun Quality, Shell or A.P. Shot Quality ALLOY STEEL WIRE Aircraft Quality Bearing Quality Special Surface Quality COLD FINISHED ALLOY STEEL BARS Regular Quality Aircraft Quality or Steel Subject to Magnetic Particle Inspection Axle Shaft Quality Bearing Shaft Quality Cold Heading Quality Special Cold Heading Quality Rifle Barrel Quality, Gun Quality, Shell or A.P. Shot Quality LINE PIPE OIL COUNTRY TUBULAR GOODS STEEL SPECIALTY TUBULAR GOODS Pressure Tubing Mechanical Tubing Stainless and Heat Resisting Pipe, Pressure Tubing, and Mechanical Tubing Aircraft Tubing Pipe

[a] In the case of certain qualities, phosphorus and sulfur are ordinarily furnished to lower limits than the specified maximum. For details, refer to the appropriate AISI Manual.

[b] Detailed description of many of the categories listed in this table appear in an appropriate section of the AISI manual.