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Учебное пособие для практических занятий

по английскому языку

STRUCTURE AND PROPERTIES OF STEELS AND CAST IRONS

Textbook for practical classis in English

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Пособие содержит ряд текстов, необходимых для закрепления материала, излагаемого на русском языке по соответствующей специальности, расширения словарного запаса студентов, навыков работы с научными текстами, развития письменной и устной речи.

Для студентов специальности "Конструирование и проектирование изделий из композиционных материалов" и "Информационные (компьютерные) технологии проектирования изделий из композиционных материалов".

Textbook contains texts necessary for material revision, which is delivered in Russian according students educational specialty, for vocabulary increasing, improving skills for dealing with scientific texts, written and oral speech practice.

For students of specialty "Design and manufacture of articles made of composites" and "Informational (computer) technologies of design of articles made of composites".

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ENGINEERING MATERIALS

Although there is a tremendous variety of engineering materials, the mechanical properties of each can be predicted and controlled by understanding the atomic bonding, atomic arrangement, and strengthening mechanisms. We will extensively utilize the ideas of solid solution strengthening, strain hardening, and dispersion strengthening for the ferrous and nonferrous alloys.

In ceramics and polymers the importance of atomic bonding and atomic arrangement will also be very evident. Although the strengthening mechanisms that apply to metals are less applicable to these materials, we will be able to draw many parallels between them. For example, deformation of certain polymers produces a fibrous microstructure that provides strengthening, just as in metals, but for different reasons. By producing copolymers, we in a sense provide solid solution strengthening. Phase diagrams play an important part in understanding the behavior of ceramics, although we often utilize the phase diagrams differently from the way we do in metals. We explain and control the mechanical properties of ceramics and polymers by mechanisms that do not involve dislocation movement.

Composite materials are even more difficult to categorize because of the many types and intended uses of the materials. The behavior of some of the composites can be explained in terms of dispersion strengthening. However, many composites are designed to provide special characteristics that go beyond the conventional methods for controlling the structure-property relationship.

Ferrous alloys

Metals and alloys are often divided into two groups – ferrous and nonferrous.

Ferrous alloys, which are based primarily on iron-carbon alloys, include plain-carbon steels, alloy and tool steels, stainless steels, and cast irons. These groups of ferrous alloys have a wide variety of characteristics and applications. Steel is alloy of iron and carbon in quantity up to 2.14% of alloy mass.

Steels can be classified by a variety of different systems depending on (fig. 1):

– composition, such as carbon, low-alloy or stainless steel;

– manufacturing methods, such as open hearth, basic oxygen process, or electric furnace methods;

– finishing method, such as hot rolling or cold rolling;

– product form, such as bar plate, sheet, strip, tubing or structural shape;

– deoxidation practice, such as killed, semi-killed, capped or rimmed steel;

– microstructure, such as ferritic, pearlitic and martensitic;

– required strength level, as specified in ASTM standards;

– heat treatment, such as annealing, quenching and tempering, and thermomechanical processing;

– quality descriptors, such as forging quality and commercial quality.

The American Iron and Steel Institute (AISI) defines carbon steel as follows: steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, columbium [niobium], molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

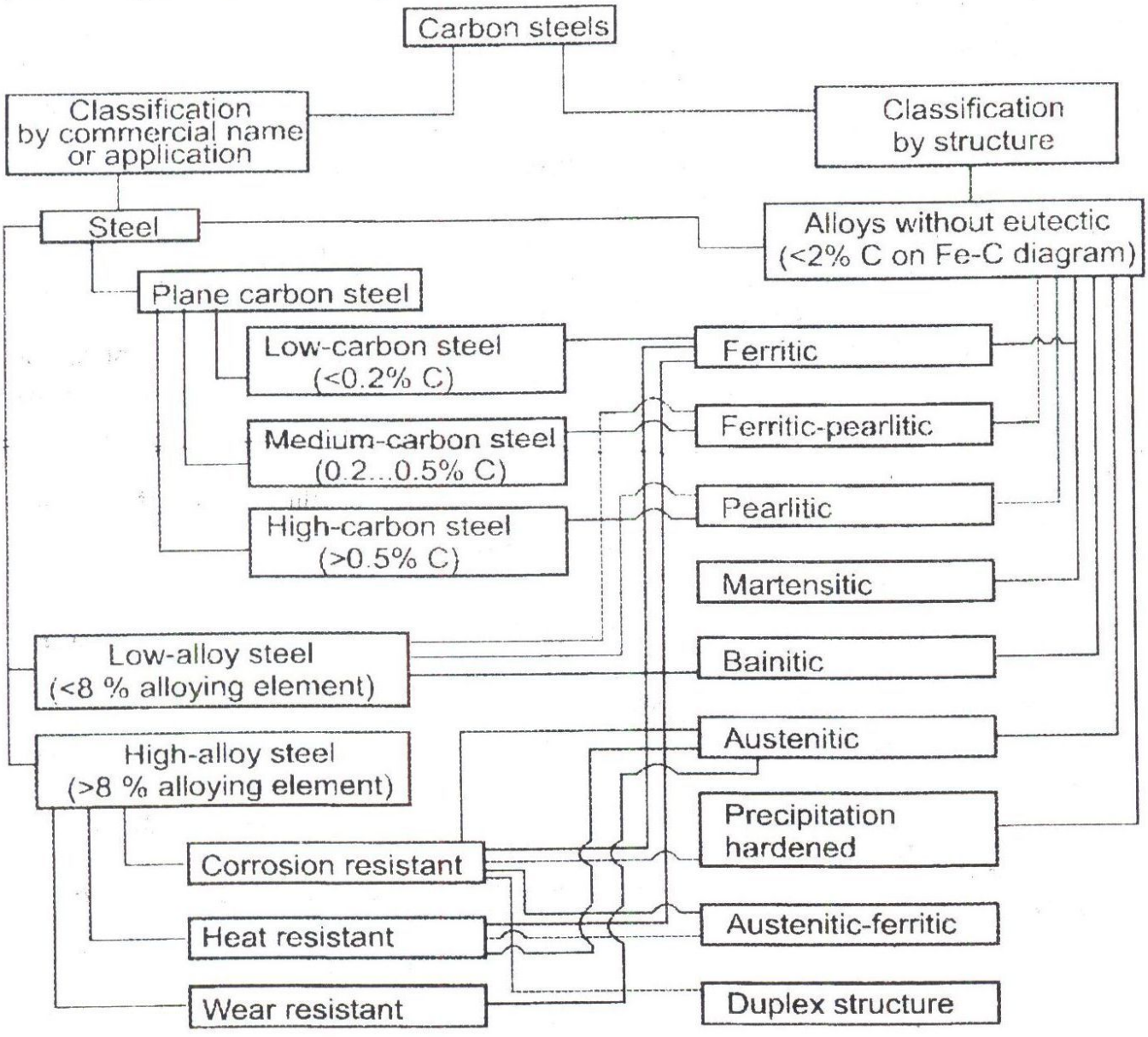


Fig. 1. Classification of carbon and low-alloy steels

Carbon steel can be classified, according to various deoxidation practices, as **rimmed**, **capped**, **semi-killed**, or **killed** steel. Deoxidation practice and the steelmaking process will have an effect on the properties of the steel. However, variations in carbon have the greatest effect on me-

chanical properties, with increasing carbon content leading to increased hardness and strength. As such, carbon steels are generally categorized according to their carbon content. Generally speaking, carbon steels contain up to 2% total alloying elements and can be subdivided into low-carbon steels, medium-carbon steels, high-carbon steels, and ultrahigh-carbon steels; each of these designations is discussed below.

As a group, carbon steels are by far the most frequently used steels. More than 85% of the steel produced and shipped in the United States is carbon steel.

Low-carbon steels contain up to 0.30% C. The largest category of this class of steel is flat-rolled products (sheet or strip), usually in the cold-rolled and annealed condition. The carbon content for these high-formability steels is very low, less than 0.10% C, with up to 0.4% Mn. Typical uses are in automobile body panels, tin plate, and wire products.

For rolled steel structural plates and sections, the carbon content may be increased to approximately 0.30%, with higher manganese content up to 1.5%. These materials may be used for stampings, forgings, seamless tubes, and boiler plate.

Medium-carbon steels are similar to low-carbon steels except that the carbon ranges from 0.30 to 0.60% and the manganese from 0.60 to 1.65%. Increasing the carbon content to approximately 0.5% with an accompanying increase in manganese allows medium carbon steels to be used in the quenched and tempered condition. The uses of medium carbon-manganese steels include shafts, axles, gears, crankshafts, couplings and forgings. Steels in the 0.40 to 0.60% C range are also used for rails, railway wheels and rail axles.

High-carbon steels contain from 0.60 to 1.00% C with manganese contents ranging from 0.30 to 0.90%. High-carbon steels are used for spring materials and high-strength wires.

Ultrahigh-carbon steels are experimental alloys containing 1.25 to 2.0% C. These steels are thermomechanically processed to produce microstructures that consist of ultrafine, equiaxed grains of spherical, discontinuous proeutectoid carbide particles.

High-Strength Low-Alloy Steels

High-strength low-alloy (HSLA) steels, or microalloyed steels, are designed to provide better mechanical properties and/or greater resistance to atmospheric corrosion than conventional carbon steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition.

The HSLA steels have low carbon contents (0.05-0.25% C) in order to produce adequate formability and weldability, and they have manganese contents up to 2.0%. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium and zirconium are used in various combinations.

HSLA can be classified as:

– **Weathering steels**, designated to exhibit superior atmospheric corrosion resistance;

– **Control-rolled steels**, hot rolled according to a predetermined rolling schedule, designed to develop a highly deformed austenite structure that will transform to a very fine equiaxed ferrite structure on cooling;

– **Pearlite-reduced steels**, strengthened by very fine-grain ferrite and precipitation hardening but with low carbon content and therefore little or no pearlite in the microstructure;

– **Microalloyed steels**, with very small additions of such elements as niobium, vanadium, and/or titanium for refinement of grain size and/or precipitation hardening;

– **Acicular ferrite steel**, very low carbon steels with sufficient hardenability to transform on cooling to a very fine high-strength acicular ferrite structure rather than the usual polygonal ferrite structure;

– **Dual-phase steels**, processed to a micro-structure of ferrite containing small uniformly distributed regions of high-carbon martensite, resulting in a product with low yield strength and a high rate of work hardening, thus providing a high-strength steel of superior formability.

The various types of HSLA steels may also have small additions of calcium, rare earth elements, or zirconium for sulfide inclusion shape control.

Low-alloy Steels

Low-alloy steels constitute a category of ferrous materials that exhibit mechanical properties superior to plain carbon steels as the result of additions of alloying elements such as nickel, chromium, and molybdenum. Total alloy content can range from 2.07% up to levels just below that of stainless steels, which contain a minimum of 10% Cr.

For many low-alloy steels, the primary function of the alloying elements is to increase hardenability in order to optimize mechanical properties and toughness after heat treatment. In some cases, however, alloy additions are used to reduce environmental degradation under certain specified service conditions.

As with steels in general, low-alloy steels can be classified according to:

– **Chemical composition**, such as nickel steels, nickel-chromium steels, molybdenum steels, chromium-molybdenum steels;

– **Heat treatment**, such as quenched and tempered, normalized and tempered, annealed.

Because of the wide variety of chemical compositions possible and the fact that some steels are used in more than one heat-treated, condition, some overlap exists among the alloy steel classifications. So four major groups of alloy steels are considered below: low-carbon quenched and tempered steels, medium-carbon ultrahigh-strength steels, bearing steels, and heat-resistant chromium-molybdenum steels.

Low-carbon quenched and tempered steels combine high yield strength (from 350 to 1035 MPa) and high tensile strength with good notch toughness, ductility, corrosion resistance, or weldability. The various steels

have different combinations of these characteristics based on their intended applications. However, a few steels, such as HY-80 and HY-100, are covered by military specifications. The steels listed are used primarily as plate. Some of these steels, as well as other, similar steels, are produced as forgings or castings.

Medium-carbon ultrahigh-strength steels are structural steels with yield strengths that can exceed 1380 MPa. Product forms include billet, bar, rod, forgings, sheet, tubing, and welding wire.

Bearing steels used for ball and roller bearing applications are comprised of low carbon (0.10 to 0.20% C) case-hardened steels and high carbon (up to 1% C) through-hardened steels.

Chromium-molybdenum heat-resistant steels contain 0.5 to 9% Cr and 0.5 to 1.0% Mo. The carbon content is usually below 0.2%. The chromium provides improved oxidation and corrosion resistance, and the molybdenum increases strength at elevated temperatures. They are generally supplied in the normalized and tempered, quenched and tempered or annealed condition. Chromium-molybdenum steels are widely used in the oil and gas industries and in fossil fuel and nuclear power plants.

Designation of Carbon and Low-Alloy Steels

A designation is the specific identification of each grade, type, or class of steel by a number, letter, symbol, name, or suitable combination. Unique to a particular steel grade, type and class are terms used to classify steel products. Within the steel industry, they have very specific uses: grade is used to denote chemical composition; type is used to indicate deoxidation practice; and class is used to describe some other attribute, such as strength level or surface smoothness.

In American Society for Testing Materials (ASTM) specifications, however, these terms are used somewhat interchangeably. In ASTM A 533, for example, type denotes chemical composition, while class indicates strength level. In ASTM A 515, grade identifies strength level; the maximum carbon content permitted by this specification depends on both plate thickness and strength level. In ASTM A 302 grade denotes requirements for both chemical composition and mechanical properties. ASTM A 514 and A 5117 are specifications for high-strength quenched and tempered plate for structural and pressure vessel applications, respectively, each contains several compositions that can provide the required mechanical properties. However, A 514 type A has the identical composition limits as A 517 grade.

Chemical composition is by far the most widely used basis for classification and/or designation of steels. The most commonly used system of designation in the United States is that of the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI). The Unified Numbering System (UNS) is also being used with increasing frequency.

SAE-AISI Designations

As stated above, the most widely used system for designating carbon and alloy steels is the SAE-AISI system. As a point of technicality, there are two separate systems, but they are nearly identical and have been carefully coordinated by the two groups. It should be noted, however, that AISI has discontinued the practice of designating steels.

The SAE-AISI system is applied to semi-finished forgings, hot-rolled and cold-finished bars, wire rod and seamless tubular goods, structural shapes, plates, sheet, strip, and welded tubing.

Carbon steels contain less than 1.65% Mn, 0.60% Si, and 0.60% Cu; they comprise the 1xxx groups in the SAE-AISI system and are subdivided into four distinct series as a result of the difference in certain fundamental properties among them.

Designations for merchant quality steels include the prefix M. A carbon steel designation with the letter B inserted between the second and third digits indicates the steel contains 0.0005 to 0.003% B. Likewise, the letter L inserted between the second and third digits indicates that the steel contains 0.15 to 0.35% Pb for enhanced machinability. Resulfurized carbon steels of the 11xx group and resulfurized and rephosphorized carbon steels of the 12xx group are produced for applications requiring good machinability. Steels that having nominal manganese contents of between 0.9 and 1.5% but no other alloying additions now have 15xx designations in place of the 10xx designations formerly used.

Alloy steels contain manganese, silicon, or copper in quantities greater than those listed for the carbon steels, or they have specified ranges or minimums for one or more of the other alloying elements. In the AISI-SAE system of designations, the major alloying elements are indicated by the first two digits of the designation. The amount of carbon, in hundredths of a percent, is indicated by the last two (or three) digits.

For alloy steels that have specific hardenability requirements, the suffix H is used to distinguish these steels from corresponding grades that have no hardenability requirement. As with carbon steels, the letter B inserted between the second and third digits indicates that the steel contains boron. The prefix E signifies that the steel was produced by the electric furnace process.

HSLA Steels. Several grades of HSLA steel are described in SAE Recommended Practice J410. These steels have been developed as a compromise between the convenient fabrication characteristics and low cost of plain carbon steels and the high strength of heat-treated alloy steels. These steels have excellent strength and ductility as-rolled.

UNS Designations The Unified Numbering System (UNS) has been developed by ASTM and SAE and several other technical societies, trade associations, and United States government agencies.

A UNS number, which is a designation of chemical composition and not a specification, is assigned to each chemical composition of a metallic

alloy. The UNS designation of an alloy consists of a letter and five numerals. The letters indicate the broad class of alloys; the numerals define specific alloys within that class. Existing designation system, such as the AISI-SAE system for steels, have been incorporated into UNS designations. UNS is described in greater detail in SAE J1086 and ASTM E 527.

AMS Designation

Aerospace Materials Specifications (AMS), published by SAE, are complete specifications that are generally adequate for procurement purposes. Most of the AMS designations pertain to materials intended for aerospace applications; the specifications may include mechanical property requirements significantly more severe than those for grades of steel having similar compositions but intended for other applications. Processing requirements, such as for consumable electrode remelting, are common in AMS steels.

ASTM Specifications. The most widely used standard specifications for steel products in the United States are those published by ASTM. These are complete specifications, generally adequate for procurement purposes. Many ASTM specifications apply to specific products, such as A 574 for alloy steel socket head cap screws. These specifications are generally oriented toward performance of the fabricated end product, with considerable latitude in chemical composition of the steel used to make the end product.

ASTM specifications represent a consensus among producers, specifiers, fabricators, and users of steel mill products. In many cases, the dimensions, tolerances, limits, and restrictions in the ASTM specifications are similar to or the same as the corresponding items of the standard practices in the AISI Steel Products Manuals.

Many of the ASTM specifications have been adopted by the American Society of Mechanical Engineers (ASME) with little or no modification; ASME uses the prefix S and the ASTM designation for these specifications. For example, ASME-SA213 and ASTM A 213 are identical.

Steel products can be identified by the number of the ASTM specification to which they are made. The number consists of the letter A (for ferrous materials) and an arbitrary, serially assigned number. Citing the specification number, however, is not always adequate to completely describe a steel product. For example, A 434 is the specification for heat-treated (hardened and tempered) alloy steel bars. To completely describe steel bars indicated by this specification, the grade (SAE-AISI designation in this case) and class (required strength level) must also be indicated. The ASTM specification A 434 also incorporates, by reference, two standards for test methods (A 370 for mechanical testing and E 112 for grain size determination) and A 29, which specifies the general requirements for bar products.

SAE-AISI designations for the compositions of carbon and alloy steels are sometimes incorporated into the ASTM specifications for bars, wires,

and billets for forging. Some ASTM specifications for sheet products include SAE-AISI designations for composition. The ASTM specifications for plates and structural shapes generally specify the limits and ranges of chemical composition directly, without the SAE-AISI designations.

General Specifications. Several ASTM specifications, such as A 20 covering steel plate used for pressure vessels, contain the general requirements common to each member of a broad family of steel products. These general specifications are often supplemented by additional specifications describing a different mill form or intermediate fabricated product.

European and Japanese Designation Systems

Below some basics of European and Japanese designation systems are explained.

DIN standards are developed by Deutsches Institut fur Normung in the Federal Republic of Germany. All West German steel specifications are preceded by the uppercase letters DIN followed an alphanumeric or numeric code. The latter method, known as the Werkstoff number, uses numbers only with a decimal point after the first digit.

JIS standards are developed by the Japanese Industrial Standards Committee, which is part of the Ministry of International Trade and Industry in Tokyo. The JIS steel specifications begin with the uppercase letters JIS and are followed by an uppercase letter (G in the case of carbon and low-alloy steels) designating the division (product form) of the standard. This letter is followed by a series of numbers and letters that indicate the specific steel.

British standards (BS) are developed by the British Standards Institute in London, England. Similar to the JIS standards, each British designation includes a product form and an alloy code.

AFNOR standards are developed by the Association Francaise de Normalisation in Paris, France. The correct format for reporting AFNOR standards is as follows. An uppercase NF is placed to the left of the alphanumeric code. This code consists of an uppercase letter followed by a series of digits, which are subsequently followed by an alphanumeric sequence.

UNI standards are developed by the Ente Nazionale Italiano di Unificazione in Milan, Italy. Italian standards are preceded by the uppercase letter UNI followed by a four-digit product form code subsequently followed by an alphanumeric alloy identification.

Swedish standards (SS) are prepared by the Swedish Standards Institution in Stockholm. Designations begin with the letters SS followed by the number 14 (all Swedish carbon and low-alloy steels are covered by SS14). What subsequently follows is a four digit numerical sequence similar to the German Werkstoff number.

Classification of Stainless Steels

Stainless steels are iron-based alloys containing at least 10.5% Cr. Few stainless steels contain more than 30% Cr or less than 50% Fe. They achieve their stainless characteristics through the formation of an invisible

and adherent chromium-rich oxide surface film. This oxide forms itself in the presence of oxygen.

Other elements added to improve characteristics include nickel, molybdenum, copper, titanium, aluminum, silicon, niobium, nitrogen, sulfur, and selenium. Carbon is normally present in amounts ranging from less than 0.03% to over 1.0% in certain martensitic grades.

The selection of stainless steels may be based on corrosion resistance, fabrication characteristics, availability, mechanical properties in specific temperature ranges and product cost. However, corrosion resistance and mechanical properties are usually the most important factors in selecting a grade for a given application.

Stainless steels are commonly divided into five groups: martensitic stainless steels, ferritic stainless steels, austenitic stainless steels, duplex (ferritic-austenitic) stainless steels, and precipitation-hardening stainless steels.

The development of **precipitation-hardenable stainless steels** was spearheaded by the successful production of Stainless W by U.S. Steel in 1945. The problem of obtaining raw materials has been a real one, particularly in regard to nickel during 1950s when civil wars raged in Africa and Asia, prime sources of nickel, and Cold War politics played a role because Eastern-bloc nations were also prime sources of the element. This led to the development of a series of alloys (AISI 200 type) in which manganese and nitrogen are partially substituted for nickel. These stainless steels are still produced today.

Over the years, stainless steels have become firmly established as materials for cooking utensils, fasteners, cutlery, flatware, decorative architectural hardware, and equipment for use in chemical plants, dairy and food-processing plants, health and sanitation applications, petroleum and petrochemical plants, textile plants, and the pharmaceutical and transportation industries. Some of these applications involve exposure to either elevated or cryogenic temperatures; austenitic stainless steels are well suited to either type of service.

Modifications in composition are sometimes made to facilitate production. For instance, basic compositions are altered to make it easier to produce stainless steel tubing and casting. Similar modifications are made for the manufacture of stainless steel welding electrodes; here combinations of electrode coating and wire composition are used to produce desired compositions deposited weld metal.

Martensitic stainless steels are essentially alloys of chromium and carbon that possess a distorted body-centered cubic (bcc) crystal structure (martensitic) in the hardened condition. They are ferromagnetic, hardenable by heat treatments, and are generally resistant to corrosion only to relatively mild environments. Chromium content is generally in the range of 10.5 to 18%, and carbon content may exceed 1.2%. The chromium and carbon contents are balanced to ensure a martensitic structure after hardening.

General corrosion is often much less serious than localized forms such as stress corrosion cracking, crevice corrosion in tight spaces or un-

der deposits, pitting attack, and intergranular attack in sensitized material such as weld heat-affected zones. Such localized corrosion can cause unexpected and sometimes catastrophic failure while most of the structure remains unaffected, and therefore must be considered carefully in the design and selection of the proper grade of stainless steel.

Corrosive attack can also be increased dramatically by seemingly minor impurities in the medium that may be difficult to anticipate but that can have major effects, even when present in only part-per-million concentrations; by heat transfer through the steel to or from the corrosive medium; by contact trimmed only on the ends.

Stainless steels are available in the form of plate, sheet, strip, foil, bar, wire, semi-finished products, pipes, tubes, and tubing.

Sheet. Sheet is a flat-rolled product in coils or cut lengths at least 610 mm wide and less than 4.76 mm thick. Stainless steel sheet is produced in nearly all types except the free machining and certain martensitic grades. Sheet from the conventional grades is almost exclusively produced on continuous mills. Hand mill production is usually confined to alloys that cannot be produced economically on continuous mills, such as certain high-temperature alloys.

The steel is cast in ingots, and the ingots are rolled on a slabbing mill or a blooming mill into slabs or sheet bars. The slabs or sheet bars are then conditioned prior to being hot rolled on a finishing mill. Alternatively, the steel may be continuous cast directly into slabs that are ready for hot rolling on a finishing mill. The current trend worldwide is toward greater production from continuous cast slabs.

Sheet produced from slabs on continuous rolling mills is coiled directly off the mill. After they are descaled, these hot bands are cold rolled to the required thickness and coils off the cold mill are either annealed and descaled or bright annealed. Belt grinding to remove surface defects is frequently required at hot bands or at an intermediate stage of processing. Full coils or lengths cut from coils may then be lightly cold rolled on either dull or bright rolls to produce the required finish. Sheet may be shipped in coils, or cut sheets may be produced by shearing lengths from a coil and flattening them by roller leveling or stretcher leveling.

Strip. Strip is a flat-rolled product, in coils or cut lengths, less than 610 mm wide and 0.13 to 4.76 mm thick. Cold finished material 0.13 mm thick and less than 610 mm wide fits the definitions of both strip and foil and may be referred to by either term.

Cold-rolled stainless steel strip is manufactured from hot-rolled, annealed, and pickled strip (or from slit sheet) by rolling between polished rolls. Depending on the desired thickness, various numbers of cold rolling passes through the mill are required for effecting the necessary reduction and securing the desired surface characteristics and mechanical properties.

Hot-rolled stainless steel strip is a semi-finished product obtained by hot-rolling slabs or billets and is produced for conversion to finished strip by cold rolling.

Strip of all types of stainless steel is usually either annealed or annealed and skin passed, depending on requirements. When severe forming, bending, and drawing operations are involved, it is recommended that such requirements be indicated so that the producer will have all the information necessary to ensure that he supplies the proper type and condition.

Experience in the use of stainless steels indicates that many factors can affect their corrosion resistance. Some of the more prominent factors are:

– chemical composition of the corrosive medium including impurities;
– physical state of the medium-liquid, gaseous, solid, or combinations thereof;
– temperature and its variations;
– aeration and ionization of the medium;
– oxygen and bacteria content of the medium;
– repeated formation and collapse of bubbles in the medium;
– relative motion of the medium with respect to the steel;
– chemical composition of the metal;
– nature and distribution of microstructural constituents etc.

Plate. Plate is a flat-rolled or forged product more than 250 mm (10 in.) in width and at least 4.76 mm (0.1875 in.) in thickness. Exceptions include highly alloyed ferritic stainless steels, some of the martensitic stainless steels, and a few of the free-machining grades. Plate is usually produced by hot rolling from slabs that have been directly cast or rolled from ingots and that usually have been conditioned to improve plat surface. Some plate may be produced by direct rolling from ingot.

For strip, edge condition is often more important than it usually is for sheet. Strip can be furnished with various edge specifications:

– Mill edge (as produced, condition unspecified);
– No.1 edge (edge rolled, rounded, or square);
– No.3 edge (as slit);
– No.5 edge (square edge produced by rolling or filing after slitting).

Foil. Foil is a flat-rolled product, in coil form, up to 0.13 mm thick and less than 610 mm wide. Foil is produced in slit widths with edge conditions corresponding to No.3 and No.5 edge conditions for strip. Foil is made from types 201, 202, 301, 302, 304, 304L, 305, 316, 316L, 321, 347, 430, and 442, as well as from certain proprietary alloys.

The finishes, tolerances, and mechanical properties of foil differ from those of strip because of limitations associated with the way in which foil is manufactured. Nomenclature for finishes, and for width and thickness tolerances, vary among producers.

Bar. Bar is a product supplied in straight lengths; it is either hot or cold finished and is available in various shapes, sizes, and surface finishes. This category includes small shapes whose dimensions do not exceed 75 mm and, second, hot-rolled flat stock at least 3.2 mm thick and up to 250 mm wide.

Hot-finished bar is commonly produced by hot rolling, forging, or pressing ingots to blooms or billets of intermediate size, which are subsequently hot rolled, forged, or extruded to final dimensions.

Applications of structural steels

The structural steels can be grouped conveniently on the basis of tensile strength. However, the dividing lines between the classes are ill defined owing to the wide variation in properties obtained from one steel by varying the heat-treatment, and the ruling section in which the properties are required.

The basis of design of machine components generally fall into either static or dynamic loading. For static loading the proof stress should be used with a safety factor of 2 or less. For dynamic loading the working stresses must be related to the fatigue limit, which is about 55% of tensile strength for mild steel, but only 50% at 770 MPa and 40% at 1540 MPa tensile strength. Notch sensitivity is also very important.

Structural steels below 680 MPa tensile

The main objective of steels in this class is to enable lighter structures to be built by the use of relatively high tensile steels, while retaining as far as possible the highly desirable properties. Properties include easy workability, adaptability and insensitivity to faulty manipulation possessed by mild steel. These steels may be used in the hot rolled condition.

Four characteristics are important: yield strength for design, notch ductility to avoid brittle fracture, weldability, cost.

From the point of view of cost, therefore, quench and tempering processes on thick plates and sections are usually ruled out. However, the installation of special equipment, such as roller quench presses, may make the technique an alternative to expensive alloy additions.

Further, although killed steels are established in European technology, balanced steels remain in favor in UK because hot top practice is not widely used and a greater yield is obtained in balanced steels. Increased use of continuous casting may affect this in the future.

The most popular types are those with manganese raised to 1.3...1.7% with carbon 0,2-0,4%, but for welding the carbon is kept low. The American "Corten A" Steel has a composition of (in percent): C - 0.12; Si - 0.5; Cu - 0.5; Cr - 0.8; P - 0.1 and Mn - 0.5%. Although the tensile strength is less than 494 MPa the yield is in the region of 371 MPa.

The combination of copper and phosphorus also increases the resistance to atmospheric corrosion, which is important when thinner plates are used. The original steel "A" suffers a decrease in yield strength and notch ductility in thickness over 25 mm, to overcome which "Corten B" was developed (in percent): C - 0.14; P - 0.04; Mn - 1.1; Cr - 0.5; Cu - 0.4; V - 0.1; B - 0.1; Al - 0.02.

The addition of 0.5 nickel and 0,25 % molybdenum to a manganese steel gives a good general purpose steel (785 M 19). Fortiweld steel containing Mo 0.5%; B 0.003%; C, 0.11% has a tensile strength of 618 MPa and is readily welded since it transforms in the bainitic region.

Pearlite Reduced Steel. Pearlite increases the tensile strength but not the yield stress, and since it raises the brittle-ductility transition tem-

perature, there is a good case for reducing the carbon content. Low carbon steels (< 0.15% C) strengthened with Mn+Nb and control rolled have good weldability and toughness and are called Pearlite Reduced Steel.

Grain refinement. Decreasing the ferrite grain size significantly increases both yield strength and notch ductility without increasing the carbon equivalent, which affects weldability. Fine grained steels using Al N have to be produced as killed steel with low yield. Niobium and vanadium have a lower affinity for oxygen than aluminium and can be used in semi-killed steels, an economic advantage. Since 1960 about 0.30...0.1% Nb forming Nb_3C_4 has been increasingly used as a grain refiner and precipitation hardening element and is the basis of several weldable steels.

Precipitation Hardening. In Niobium steels Nb_4C_3 dissolves above 1250°C, large grains and subsequent precipitation hardening is pronounced, but brittle transition temperature is high. Normalizing at 900...950°C forms a precipitate, resulting in a grain refined steel, slight precipitation hardening, but low impact transition temperature.

By controlled hot rolling from 1250°C to a low finishing temperature (900°C) with a substantial amount of deformation in range 950-850°C, a fine ferrite grain size is obtained in sections up to 25 mm, with a minimum yield of 463 MPa due to dispersion hardening occurring in the ferrite during cooling.

Thick plates present difficulties in getting the required drop in rolling temperature. Holding at an intermediate temperature produced a partially recrystallised structure of large grains surrounded by small ones. The final structure is of very mixed size with poorer mechanical properties.

It is possible to quench similar steels from 1050°C to form a low carbon martensite or with lower carbon content, acicular ferrite followed by tempering to give higher properties. Nicuage steel (C 0.06%, Ni 1%, Cu 1.1%, Nb 0.02%, Mn 0.5%) rolled and aged at 500...570°C has a yield of 600 MPa and a tensile strength of 700 MPa, elongation 23% and 34...82 Joules charpy V notch impact at -20°C coupled with good weldability and corrosion resistance.

Steels above 680 MPa tensile

Relative to the steels just discussed, those in this group are designed solely for their mechanical properties, which depend on accurately controlled heat-treatment.

In covering bars, billets and forging in this strength range rationalized steel specifications to conserve essential alloys. The basic principle was the specifying of mechanical properties related to size of bar when heat-treated rather than chemical composition. The cheapest steel will develop the requisite properties in the limited ruling section of the component used although other factors may modify the choice such as forging characteristics and die wear, machinability and ease of heat treatment.

Suitable compositions within the range have to be chosen in relation to mass. Thus nickel alone has a low efficiency in spite of its pre-war popularity. A conception new to many engineers is that the actual steel used for

a given tensile strength **depends on the size of the article at the time it is heat-treated**.

In 1970 the six digit designation system was adopted. The first three digits refer to alloy type, the fifth and sixth digits represent 100 times the mean carbon content. At the fourth digit letters, A, M and H indicate if the steel is supplied to analysis, mechanical property or hardenability requirements, which are the new alternative methods.

Ultra-high Tensile Structural Steels

Interest in (1544-2160 MPa) tensile steels for use in the aircraft industry is leading to the development of modified steels which can be used up to 400°C in supersonic aircraft and which possess adequate ductility and notch impact strength. Vacuum arc or Electro-slag melting of some of these steels reduces inclusions and impurities and gives a more suitable cast structure. As a result, the transverse properties of the resultant forging tend to be superior to those from conventionally air cast ingots. A few typical compositions of 0,37% C 1850 MPa steels are given below.

Steel	Si	Mn	Ni	Cr	Mo	V	T_t, °C	ε, %
3% Cr-Mo-V	0.2	0.5	0.2	3.0	0.9	0.2	300	8
Rex 539 Si-Mn-Ni	1.6	1.6	1.8	0.1	0.4	0.2	350	7
H50	1.1	0.5	–	5.0	1.3	1.1	560	7
SAE 4340	0.3	0.6	1.8	0.8	0.25	–	220	9
Si-Cu steel	2.0	Cu=2	–	–	0.7	0.2	400	9

T_t– tempering temperature; ε–relative eiongation.

These are based on Ni-Cr-Mo or use silicon with nickel or copper. Silicon reduces the expansion in g-martensite change and hence reduces risk of quench cracking; while copper is useful for producing secondary hardening at 450...550°C.

With such low alloy contents protection against rust by cadmium plating or aluminium spraying is necessary. Unfortunately, cleaning and plating processes can introduce hydrogen into the metal and embattlement at the high strength level can be serious. Such embattlement becomes evident under sustained loading, for example a 2,5 Ni Cr Mo steel hardened to 2220 MPa tensile broke within 100 hours at MPa and in 12 hours at 1544 MPa sustained load in air and much shorter times in corrosive media. With such high tensile steels it is highly desirable to (a) avoid notches, (b) to reduce internal stresses by tempering at as high a temperature as possible, (c) minimize the introduction of hydrogen (abrasive blasting preferred). Cadmium coats should be avoided for service above 250°C. For other high strength steels refer to precipitation hardening transformation and controlled transformation stainless steels.

Maraging Steels

These use the martensitic reaction which end high hysteresis occurs in Fe-Ni alloys. They are iron based alloys containing 18 Ni 8 Co 5 Mo with

small amounts of Al and Ti and less than 0,03% C, which makes such a difference to fracture toughness and ease of welding. The strength is maintained with increase in section thickness and also up to 350°C. Alloy cost is balanced by lower production cost, virtually no risk of decarburisation, distortion or cracking. These steels are used for airframe and engine components, injection moulds and dies.

On cooling from the austenitic condition the alloy transforms to a fine lath type martensite, and precipitation hardening is induced by "maraging" at 480°C. Many types of precipitates have been reported (e.g. Ni_3TiAl) but the main hardener is probably orthorhombic Ni, Mo, the solubility of which is probably reduced by Cobalt. The steels have high fracture toughness, K_{1c} due to a combination of fine grain size of the martensite and the high dislocation density, leading to fine precipitation. The steels can be nitrided. The corrosion resistance is only slightly improved but the 12% Cr variety has been developed for corrosion resistance.

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Alloy spring steels of the chromium-vanadium (Cr 1%; V 0.2%; C 0,6%), (Ni 0,5%; Cr 0,5%; Mo 0,2%; C 0,6%) and silico-manganese (Si 2%; Mn 1%) types are also oil hardened from 80°C and tempered at 480°C to give a Vicker`s hardness of 400, tensile strength of 1390 MPa, with appreciable ductility. Springs are made from steel treated as follows:

a) Cold drawn patented steel wire;

b) Cold worked annealed steel;

c) Quenched and tempered (0.5...1.0%C) steel (VPN 340-430). After having been formed, the springs, (a, b, c) are only given a low temperature temper (170...300°C) to relieve forming stresses;

d) Annealed steel. After having been formed, the spring is then quenched and tempered. All heavy springs are formed hot and frequently hardened immediately after forming. Aero-engine valve-spring steel must be free from any kind of surface defect. Springs for watches and aircraft instruments, Bourden tubes, diaphragms etc. are often made from Ni-span containing 42% Ni, 5% Cr, 2.3% Ti, 0.02% C, 0.55 Al which has low mechanical hysteresis and can be heated to reduce the effect of changes in service temperatures.

High and low thermal expansion steels

There are cases in engine construction where steel has to work in conjunction with light alloys, such as cylinder-head bolts, valve seating, or cylinder liners in aero engines. The comparatively high thermal expansivity of aluminium leads to looseness unless the steel has a similar coefficient of expansion. The austenitic steel of the following composition 0,59% C; 12% Ni; 5.1 Mn; 3,4 Cr has a thermal expansion of $21 \cdot 10^{-6}$ per degree C up to 400°C, which is only slightly lower than that of aluminium, and it combines good mechanical properties with resistance to abrasion.

Cold rolled austenitic stainless steel is another alternative. Where an abnormally low coefficient of expansion is required, Invar, containing 36% Ni, is used.

НАУКОВО-ТЕХНІЧНА БІБЛІОТЕКА
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Ball-race steel. A typical composition is 1.0 C; 0.5 Mn; 1.36% Cr. After quenching in oil from 810°C the steel is usually tempered at 100-200°C to reduce hardening stresses and cracks in grinding. Tempering at 100°C also increases the hardness slightly.

Creep-resisting steels for use at steam temperatures

The use of higher temperatures and pressures in modern power stations has necessitated the use of special steels for the pipe-lines and other parts. The essential characteristic of these steels is higher resistance to creep at temperatures varying from 400° to 565°C. A common steel used for this purpose is one containing approximately 0,55% molybdenum with a carbon content of approximately 0,15...0,2%.

Failures of pipes have occurred in America, which have been traced to the formation of a network of graphite in the heat-affected zone of the pipe adjacent to the weld. Heating the steel to approximately 750°C appears to accelerate the formation of this graphite, which is also largely affected by the process of making a steel, particularly as regards the use of aluminium as a deoxidizes, which is more commonly used in America than Great Britain. It has been found that a small addition of a carbide stabilizer, such as 1,0% chromium, is beneficial in minimizing this trouble.

The addition of 25% V raises the creep resistance still further. The 1% Cr Mo V steels currently in use are chiefly of two types, those for steam-chest castings where due to welding considerations the carbon level is limited to 0,5%; and those used in high and intermediate pressure rotors in which the need for improved hardenability with large rotors has necessitated carbon levels of 0,25...0,30%.

Creep seems to be related to the uniformity of the V_4C_3 and its inter-particle spacing, which should be less that 1000 . This distribution is affected by cementite, which promotes regions denuded of V_4C_3, and to minimize this problem the cooling rate from the austenitising temperature must be such as to give an entirely upper bainitic structure.

Low-carbon 3 and 6% chromium steels containing 0,5% molybdenum have carbides which resist hydrogen attack and embattlement at elevated temperatures and pressures and are useful in synthetic ammonia plants and oil refineries. Columbium or titanium is sometimes added to minimize the air-hardening tendencies in the steel by forming carbides less soluble at heat-treating temperatures. Air-hardening still occurs after welding but air-cooling from 800°C is sufficient to soften the steel. Resistance to corrosion and oxidation increases with the chromium content; the elongation at rupture is also increased.

Alloyed tool and die steels

Standard BS 4659:1971 groups tool steels into six types: high speed, hot work, cold work, shock resisting, special purpose, water hardening.

The designations follow the AISI with the addition of B. Thus BTI and BMI designates high speed steel of tungsten and molybdenum grades re-

spectively.

Non-shrinking steels. This term refers to steels which show little change in volume from the annealed state when hardened and tempered at low temperatures. In non-shrinking steels the volume changes counterbalance each other, and such steels are required for master tools, gauges and dies which must not change size when hardened after machining in the annealed condition. The cheapest non-shrinkage steel contains 0,9% carbon and about 1,7% manganese. A better steel has the composition: 1.0% C; 0.95% Mn; 0.5% W; 0.75% Cr; 0.2% V.

Both steels are oil quenched from 780° to 800°C and tempered 224...245°C. High carbon 5% and 12% chromium steels are also used for non-distortion.

Finishing tool steel. While high-speed steels are very efficient with heavy cuts and high speeds they are incapable, at slow speeds and lighter cuts, of holding the keen edge necessary for obtaining a very smooth finish on certain articles. Special steels have been produced for this purpose, known as finishing steels, which are capable of retaining a keen cutting edge for much longer periods than carbon steel used under similar conditions. The usual type has the approximate composition: 1.1...1.4% C; 4% W; 0.7...1.5% Cr; 0.3% V.

After preheating to 650°C it is water hardened at 820...840°C and immediately tempered at 150...180°C. Anneal at 750°C. Tungsten steels containing 1 to 5,5% and 1 to 1,3% carbon are used for twist drills, taps, milling cutters, drawing dies and also tools for rifling gun barrels, boring cylinders and expanding tubes, which require long continuous cutting without interruption for regrinding. They are tempered at 200...230°C.

Cold die steels. The standard oil hardening die steels contain 1% C, 1% Mn, 0.3...1.6% W, 0.5% Cr, hardened from 800°C and immediately tempered at 170...250°C. For cold obtrusion punches high-speed steels are satisfactory, e.g. 6W6Mo.

High carbon-chromium steel (2% C, 13% Cr, 0...25% Mn, 0...6% Si) oil-hardened at 950...1000°C and tempered at 480°C during 2 hrs has good resistance to oxidation at elevated temperatures, high hardness and good wearing properties. It is suitable for intricate sections, dies for blanking, coining, toller threading and drop forging hard materials. The structure is martensitic on cooling in air but the carbides can be precipitated and the steel softened by very slow cooling from 840°C.

High tungsten-chromium steel. Steel with the composition (0.3% C; 0,3% Mn; 10% W; 3%Cr; 0.3% V; 0,3% Mo) oil-quenched at 1150°C, tempered at 570°C and annealed at 850°C is the best type of steel for hot work except where resistance to scaling or oxidation is important. It is used for hot-drawing, hot-forging, extrusion dies and dies for die casting aluminium, brass and zinc alloys. Die-casting die steels often fall through surface cracking caused by cyclic expansion and contraction, aggravated by the erosive action of the molten metal.

Sensitivity of die steels to distortion during heat-treatment is largely af-

fected by directionality and particle size of the carbides in the microstructure. Expansion is greatest in the direction of carbide stringers. Fine random distribution of carbides are therefore desirable. For die casting and extrusion dies molybdenum containing 0,5% Ti+0,08% Zr is useful in critical applications. Thermal conductivity, resistance to thermal shock and attack by molten metal is high and no heat treatment is required. Nimonic 80(a) and 90 have also been used satisfactorily for dies and inserts. Die block steels for drop forging have been standardized into four following types: 0.6 carbon steel; 1% nickel, 0.6 C; 1.5 Ni, 0.7 Cr, 0.6 C; 1.5 Ni, 0.7 Cr, 0.6 C, 0.25 Mo.

High-speed steels for shear blades

Some examples of alloy steels used for shearing are given in table 1.

The evolution of high-speed cutting tools commenced with the production of Mushet's self-hardening tungsten-manganese steel in 1860. The possibilities of such steels for increased rates of machining were not fully appreciated until 1900, when Taylor and White developed the forerunner of modern high-speed steels. In addition to tungsten, chromium was found to be essential and a high hardening temperature to be beneficial. The -steel resisted tempering up to 600°C. This allowed the tool to cut at speeds of 80-50 meters per minute with its nose at a dull red temperature and it was one of the astonishing exhibits at the Paris Exhibition of 1900.

Table 1. Shear blade steel

Type of work	C	Cr	V	W
Cold shearing for heavy materials	0.85		0.2	–
	0.55	Mn=0.8	Mn=0.8	–
Cold shearing for light materials	1.0	–	0.2	–
	0.7	0.9	0.2	–
	0.6	4	1	18
	2.2	12	–	–
Shears for hot work	0.5	1.2	0.2	2
	0.4	3.5	0.4	10

The main constituents in high-speed steel are 14 or 18% tungsten, 3 to 5% chromium and 0,6% carbon. Other elements are frequently added to modern steels which vary considerably in composition and cost. 0,09-0,15% sulfur is sometimes added to give free machining for unground form tools.

Vanadium improves the cutting qualities of the tools and increases the tendency to air hardening. Cobalt, often added to the "super high-speed" steel, raises the temperature of the solidus and enables a higher hardening temperature to be used, with consequent greater solution of carbon. Secondary hardness is marked in such steels, and this permits the use of deep cuts at fast speeds. The molybdenum steel is susceptible to decarburisation. The high vanadium steel is somewhat brittle, but is excellent for cutting very abrasive materials.

Cast Irons

The term cast iron, like the term steel, identifies a large family of ferrous alloys. Cast irons are multicomponent ferrous alloys. They contain major (iron, carbon, silicon), minor (<0.01%), and often alloying (>0.01%) elements.

Cast iron has higher carbon and silicon contents than steel. Because of the higher carbon content, the structure of cast iron, as opposed to that of steel, exhibits a rich carbon phase. Depending primarily on composition, cooling rate and melt treatment, cast iron can solidify according to the thermodynamically metastable Fe-Fe_3C system or the stable Fe-graphite (Gr) system.

When the metastable path is followed, the rich carbon phase in the eutectic is the iron carbide; when the stable solidification path is followed, the rich carbon phase is graphite. Referring only to the binary Fe-Fe_3C or Fe-Gr system, cast iron can be defined as an iron-carbon alloy with more than 2% C. Important notice is that silicon and other alloying elements may considerably change the maximum solubility of carbon in austenite. Therefore, in exceptional cases, alloys with less than 2% C can solidify with a eutectic structure and therefore still belong to the family of cast iron.

The formation of stable or metastable eutectic is a function of many factors including the nucleation potential of the liquid, chemical composition, and cooling rate. The first two factors determine the graphitization potential of the iron. A high graphitization potential will result in irons with graphite as the rich carbon phase, while a low graphitization potential will result in irons with iron carbide.

The two basic types of eutectics – the stable austenite-graphite or the metastable austenite-iron carbide (Fe_3C) – have wide differences in their mechanical properties, such as strength, hardness, toughness, and ductility. Therefore, the basic scope of the metallurgical processing of cast iron is to manipulate the type, amount, and morphology of the eutectic in order to achieve the desired mechanical properties.

Classification of cast iron

Historically, the first classification of cast iron was based on its fracture. Two types of iron were initially recognised:

– **White iron**: Exhibits a white, crystalline fracture surface because fracture occurs along the iron carbide plates; it is the result of metastable solidification (Fe_3C eutectic);

– **Gray iron**: Exhibits a gray fracture surface because fracture occurs along the graphite plates (flakes); it is the result of stable solidification (Gr eutectic).

With the advent of metallography, and as the body of knowledge pertinent to cast iron increased, other classifications based on microstructural features became possible:

– **Graphite shape**: Lamellar (flake) graphite (FG), spheroidal (nodular) graphite (SG), compacted (vermicular) graphite (CG), and temper graphite (TG); temper graphite results from solid-state reaction (malleabilization.);

– **Matrix**: ferritic, pearlitic, austenitic, martensitic, bainitic (austem-

pered).

This classification is seldom used by the floor foundryman. The most widely used terminology is the commercial one. A first division can be made in two categories:

– **Common cast irons**: For general-purpose applications, they are unalloyed or low alloyed;

– **Special cast irons**: For special applications, generally high alloyed. Special cast irons differ from the common cast irons mainly in the higher content of alloying elements (>3%), which promote microstructures having special properties for elevated-temperature applications, corrosion resistance, and wear resistance. A classification of the main types of special cast irons is shown in Fig. 2.

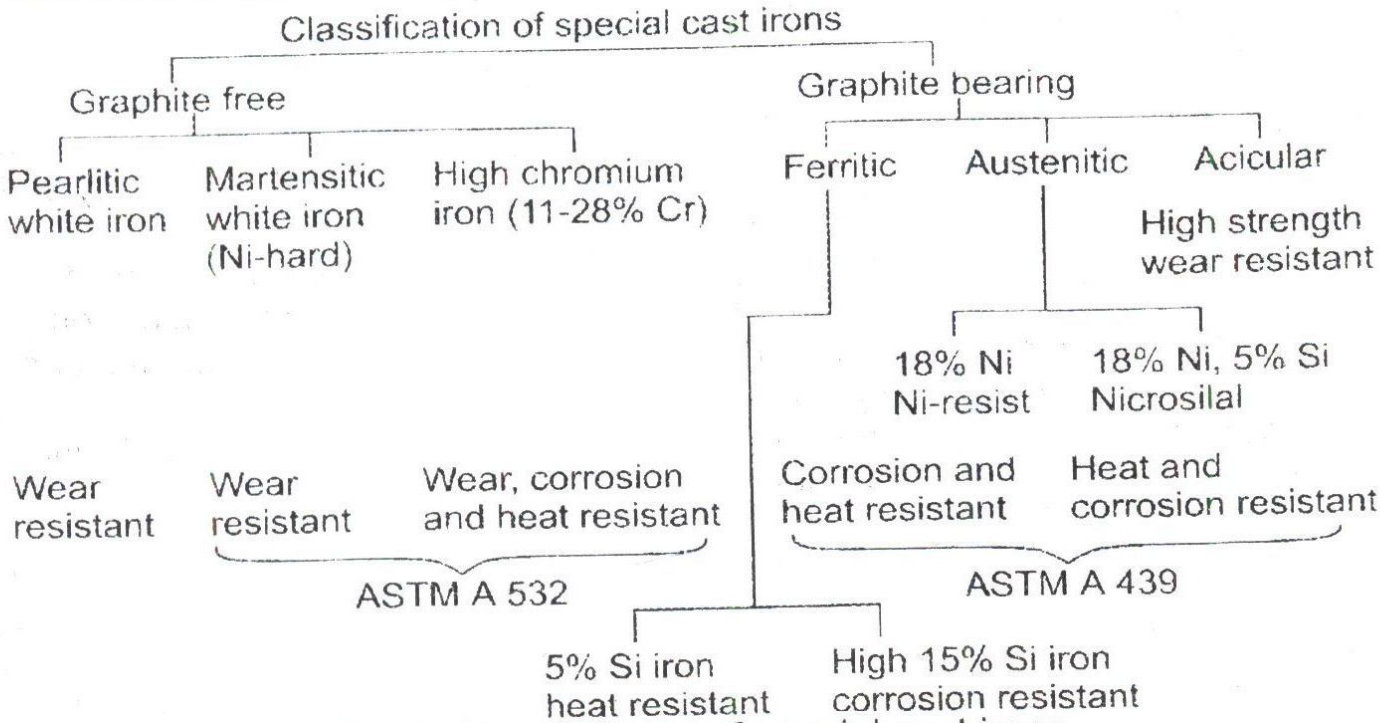


Fig. 2. Classification of special cast irons

Compared with gray iron, ductile cast iron has excellent strength, ductility, and toughness. Ductility and strength are also higher than in malleable but due to the higher silicon content in ductile iron, the toughness may be slightly lower. Typical properties arc described in Tables 2, 3.

Table 2. Grades of ductile cast iron

Grade	Tensile strength, ksi	Yield strength, ksi	Elongation, %	Matrix structure	Heat treatment
60-40-18	60	40	18	Ferrite	Annealed
65-45-12	65	45	12	Mostly ferrite	As-cast
80-55-06	80	60	6	Mostly perlite	As-cast
100-70-03	100	70	3	Perlite	Normalized
120-90-02	120	90	2	Tempered martensite	Quenched and tempered

Table 3.Comparison of compacted graphite cast iron with gray and ductile cast iron

Cast Iron	Tensile strength, psi	Yield strength, psi	% Elongation
Gray iron	20...60	–	<1.5
Compacted graphite iron			0.6
Grade A (<10% pearlite)	40	28	–
Grade B (20...80% pearlite)	50	40	–
Grade C (>80% pearlite)	65	55	–
Ductile iron	60...120	40...90	0.6

Summary

At first glance, steels appear to be an exceptionally varied and complicated group of alloys. However, the properties of steels are determined primarily by the amount, size, shape, and distribution of the cementite, which in turn are controlled by heat treatment. Spheroidizing, which produces large, spheroidal cementite, gives the softest, most ductile steel. Annealing gives a coarse pearlitic structure containing lamellar cementite. Normalizing produces a finer pearlite and improved strength. Austempering (giving bainite) or quench and temper heat treatments (giving tempered martensite) produce exceptionally fine dispersions of cementite. The most important function of alloying elements is to improve our ability to perform these heat treatments or to help make the structures that are produced more stable at high temperatures.

Stainless steels, which must contain a minimum of 12% Cr, are selected for their excellent corrosion resistance. By proper control of alloying elements and heat treatment, a variety of structures and properties can be produced.

Cast irons undergo the eutectic reaction during solidification. Depending on the reaction, either cementite and austenite or graphite and austenite form. The shape of the graphite is controlled by the addition of modifiers, such as magnesium, and inoculants, producing spheroidal, compacted, or flake graphite cast irons. Cementite is decomposed by heat treatment to produce malleable iron. Furthermore, the decomposition of austenite to ferrite, pearlite, bainite, or martensite can be achieved by controlling alloying elements, cooling rate, or heat treatment.

Annealing (cast iron). A heat treatment used to produce a ferrite matrix in a cast iron by austenitizing, then furnace cooling.

Annealing (steel). A heat treatment used to produce a soft, coarse pearlite in steel by austenitizing, then furnace cooling.

Ausforming. A thermomechanical heat treatment in which austenite is plastically deformed below the A_1 temperature, then permitted to transform to bainite or martensite.

Austempering. The isothermal heat treatment by which austenite transforms to bainite.

Austenitizing. Heating a steel or cast iron to a temperature where homogeneous austenite can form. Austenitizing is the first step in most of the heat treatments for steel and cast irons.

Carbon equivalent. Carbon plus one-third of the silicon in a cast iron.

Carburizing. A group of surface-hardening techniques by which carbon diffuses into steel. Some related processes by which nitrogen is introduced include carbonitriding, cyaniding, and nitriding.

Case depth. The depth below the surface o a steel to which hardening occurs by surface hardening and carburizing processes.

Cast iron. Ferrous alloys containing sufficient carbon so that the eutectic reaction occurs during solidification.

Chill depth. The distance from the surface in which the cast iron freezes according to the cementite reaction rather than the graphite reaction.

Chilled iron. Cast iron designed so that the surface is hard, wear-resistant white iron while the center is softer, tougher gray or ductile iron.

Compacted graphite cast iron. A cast iron treated with small amounts of magnesium and titanium to cause graphite to grow during solidification as an interconnected, coral-shaped precipitate, giving properties midway between gray and ductile iron.

Drawing. Reheating a malleable iron in order to reduce the amount of carbon combined as cementite by spheroidizing pearlite, tempering martensite, or graphitizing both.

Dual phase steels. Special steels treated to produce martensite dispersed in a ferrite matrix.

Ductile cast iron. Cast iron treated with magnesium or cerium to cause graphite to precipitate during solidification as spheres, permitting excellent strength and ductility. Also known as **nodular cast iron**.

Eutectic cell. A cluster of graphite flakes produced during solidification which are all interconnected to a common nucleus.

Fading. The loss of the nodulizing or inoculating effect in cast irons as a function of time, permitting undesirable changes in microstructure and properties.

Ferrous alloys. Metal alloys based primarily on iron, including steel, stainless steel, and cast iron.

First stage graphitization. The first step in the heat treatment of a malleable iron, during which the massive carbides formed during solidification are decomposed to graphite and austenite.

Gamma loop. A number of alloying elements in iron, including chromium, reduce the temperature range over which austenite is stable, thus producing a loop in the phase diagram.

Gray cast iron. Cast iron which, during solidification, permits graphite flakes to grow, causing low strength and poor ductility.

Hardenability. The ease with which a steel can be quenched to form martensite. Steels with high hardenability form martensite even on slow cooling.

Hardenability curves. Graphs showing the effect of cooling rate on the hardness of a steel.

Inoculation. The addition of an agent to the molten cast iron that provides nucleation sites at which graphite precipitates during solidification.

Isothermal annealing. Heat treatment of a steel by austenitizing, cooling rapidly to a temperature between the A_1 and the nose of the TTT curve, and holding until the austenite transforms to pearlite.

Jominy distance. The distance from the quenched end of a Jominy bar. The Jominy distance is related to the cooling rate.

Jominy test. The test used to evaluate hardenability. An austenitized steel bar is quenched at one end only, thus producing a range of cooling rates along the bar.

Malleable cast iron. Cast iron obtained by a lengthy heat treatment during which cementite decomposes to produce rounded clumps of graphite. Good strength and ductility are obtained as a result of this structure.

Marquenching. Quenching austenite to a temperature just above the M_s and holding until the temperature is equalized throughout the steel before further cooling to produce martensite. This process reduces residual stresses and quench cracking. Also known as **martempering**.

Mottled iron. Cast iron produced when both cementite and graphite precipitate during solidification. Mottled iron is not desirable under any conditions.

Nodulizing. The addition of magnesium to molten cast iron to cause the graphite to precipitate as spheres rather than as flakes during solidification.

Normalizing. A simple heat treatment obtained by austenitizing and air cooling to produce a fine pearlitic structure.

Process anneal. A low-temperature heat treatment used to eliminate all or part of the effect of cold working in steels.

Retained austenite. Austenite that is unable to transform into martensite during quenching because of the volume expansion associated with the reaction.

Second stage graphitization. The second step in the heat treatment of malleable irons that are to have a ferritic matrix. The iron is cooled slowly from the first stage graphitization temperature so that austenite transforms to ferrite and graphite rather than pearlite.

Spheroidite. A microconstituent containing coarse spheroidal cementite particles in a matrix of ferrite, permitting excellent machining characteristics in high-carbon steels.

Stainless steels. A group of ferrous alloys that contain at least 12% Cr, providing extraordinary

corrosion resistance.

Tempered martensite. The mixture of ferrite and cementite formed when martensite is tempered.

Tool steels. A group of high-carbon steels which provide combinations of high hardness, toughness, or resistance to elevated temperatures.

Vermicular graphite. The rounded, interconnected graphite that forms during the solidification of cast iron. This is the intended shape in compacted graphite iron but is a defective shape in ductile iron.

White cast iron. Cast iron which produces massive amounts of cementite rather than graphite during solidification. The white irons are very hard but brittle.

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СТРУКТУРА И СВОЙСТВА СТАЛЕЙ И СПЛАВОВ

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