Chapter

1

INTRODUCTION TO COMPARING WORLD STEEL STANDARDS

Myth and Methodology When Comparing Steel Standards

When comparing steel standards from different national and international standard development organizations (SDOs), there is no such thing as *equivalent* steel standards. At best, one may be able to group *comparable* steel standards together based on some defined set of rules, which has been done in this handbook. For example, ASTM A516/A516M Grade 70 is *comparable* to JIS G3118 symbol SGV 480 and to EN 10028-2 steel name P295GH, based on chemical compositions, mechanical properties, and application. Yet they are not *equivalent* because there are differences in all three standards. Comparing steel standards is not an exact science and cannot be made into a mathematical equation where two sides of an equation are equal to one another because there will always be differences among standards.

These differences may be significant to one user but not significant to another. Therefore, this handbook uses the term *comparative* to denote similar standards that have been compared to each other. Comparative is a relative word that is inevitably dependent upon the requirements of the end user, the one who is ultimately responsible for selecting the appropriate steel for a specific application.

There are some steel standards that are shared by multiple SDOs. For example, EN ISO 4957–Tool Steels is a standard that is shared within the European Committee for Standardization (CEN) and the International Standards Organization (ISO) systems. Consequently, the data are equivalent in both systems, but there is only one standard.

There are also different standards that share the same grades of steel. For example, ASTM A485 and ISO 683-17 share seven identical bearing steel grade chemical compositions, yet there are differences in grain size, hardenability, microstructure, hardness, inspection, testing, and in other details of both standards. As a result, the seven bearing steels within these two standards are not equivalent, but they are comparable.

Comparative and Closest Match

There is also a difference between *comparative* and *closest match* when evaluating steel standards. While gathering the data for this handbook, it was difficult to decide whether to include data on a technically comparative basis or on a closest match basis as both have their merits and limitations. (See 70 % rule in EN 10020 on page 6 for a more detailed discussion.)

A technically comparative group of steels can assist the user with making a material selection based on technical merit. However, this may severely limit the number of steels that would be comparable. On the other hand, displaying the closest match data will usually increase the number of comparative steels for the user to consider but at the risk of widening the technical comparison criteria. Likewise, a strict technical comparison will provide more accurate results, but a closest match comparison will provide more data to assist the user in searching for similar steels.

There are many instances in the handbook where it would be a disservice to the reader not to include the closest match steels because there would be no comparisons otherwise. Because this broadens the technical comparison criteria, the user is warned that the data herein cannot substitute for education, experience, and sound engineering judgment after evaluating all of the specifications within each comparable standard.

In the end, there are no definitive rules that can be formulated to distinguish between *comparative* steels and *closest match* steels. Consequently, at the editor's discretion, both types of comparisons are used in this handbook. Table 1.1 is one example of the comparison process, with respect to technically comparative steels and closest match steels.

Table 1.1 lists the chemical compositions of four grades of cast alloy chromium-nickel-molybdenum (Cr-Ni-Mo) steels. If a strict technical comparison was made based on their chemical composition, none of these alloys would be comparable because their chemical compositions would differ; although there are similarities in their carbon (C), Cr, Mo, and Ni contents.

Table 1.2 shows how these four steels were divided into two separate comparative groups based on the differing Cr and Mo contents. The thin black line in Table 1.2 is the separator between the two comparative groups.

Displaying the two groups side by side also assists the user in seeing the differences and similarities among these four cast alloy steels.

Table 1.1 List of Chemical Compositions of Cr-Ni-Mo Alloy Cast Steels Before Comparison

Specification	Designation	Steel No.	UNS No.	Weight, % max, Unless Otherwise Specified*								
				C	Mn	Si	P	S	Cr	Ni	Mo	Others
ASTM A958/ A958M-14	SC 4330	---	J23259	0.28–0.33	0.60–0.90	0.30–0.60	0.035	0.040	0.70–0.90	1.65–2.00	0.20–0.30	—
JIS G5111:1991	SCNCrM 2	---	---	0.25–0.35	0.90–1.50	0.30–0.60	0.040	0.040	0.30–0.90	1.60–2.00	0.15–0.35	—
EN 10293:2015	G32NiCrMo8-5-4	1.6570	---	0.28–0.35	0.60–1.00	0.60	0.020	0.015	1.00–1.40	1.60–2.10	0.30–0.50	V 0.05 Cu 0.30
ISO 14737:2003	Grade G32NiCrMo8-5-4	---	---	0.28–0.35	0.60–1.00	0.60	0.020	0.015	1.00–1.40	1.60–2.10	0.30–0.50	V 0.05 Cu 0.30

Table 1.2 List of Chemical Compositions of Cr-Ni-Mo Cast Alloy Steels After Comparison

Specification	Designation	Steel No.	UNS No.	Weight, %, max, Unless Otherwise Specified								
				C	Mn	Si	P	S	Cr	Ni	Mo	Others
ASTM A958/ A958M-14	SC 4330	---	J23259	0.28–0.33	0.60–0.90	0.30–0.60	0.035	0.040	0.70–0.90	1.65–2.00	0.20–0.30	---
JIS G5111:1991	SCNCrM 2	---	---	0.25-0.35	0.90-1.50	0.30-0.60	0.040	0.040	0.30-0.90	1.60-2.00	0.15-0.35	---
EN 10293:2015	G32NiCrMo8-5-4	1.6570	---	0.28–0.35	0.60–1.00	0.60	0.020	0.015	1.00–1.40	1.60–2.10	0.30–0.50	V 0.05 Cu 0.30
ISO 14737:2003	Grade G32NiCrMo8-5-4	---	---	0.28–0.35	0.60–1.00	0.60	0.020	0.015	1.00–1.40	1.60–2.10	0.30–0.50	V 0.05 Cu 0.30

A classic closest match example is shown in Table 1.3, where the four grades within EN 10085 are different; on this basis, they may not belong to this comparative group. However, the Cr-Al-Mo alloys in this group typically are used as nitriding steels, and the EN 10085 steels are the closest match for this group. Excluding them would be a disservice to the user because they belong to the same application family, and its inclusion in this group will direct the user to other similar nitriding alloys.

There are many opportunities to make technical errors that may lead to inappropriate steel comparisons. For example, there are many technical decisions to make when comparing stainless steels because finding identical chemical compositions within standards from different countries is not common. Table 1.4 shows a list of comparative Cr-Ni-Mo wrought austenitic stainless steels from the United States, Europe, China, Japan, and other international locations. Note the differences in the silicon (Si), Cr, Ni, and nitrogen (N). The U.S., Chinese, and Japanese chemical compositions are more closely matched, whereas the European and international (ISO) standards are identical. These differences may affect the corrosion resistance performance in many applications, such that the user must be very careful when selecting a comparative steel based solely on data in this handbook.

In summary, if strict technical comparison is made to this type of data, few relationships among the various grades of steel would be established, and the comparison would serve no purpose. By widening the technical comparison criteria to find the closest match steels, the user must understand that these steels are not equivalent and cannot be indiscriminately substituted without first reviewing the complete current standards and securing competent technical advice prior to any decision making.

To find a balance for comparison of steels by product form, use (application), mechanical properties, chemical compositions,

Table 1.3 Chromium-Molybdenum-Aluminum (Cr-Mo-Al) Steels for Nitriding

Specification	Designation	UNS No.	Steel No.	Weight, %, max, Unless Otherwise Specified								
				C	Mn	Si	P	S	Cr	Ni	Mo	Others
ASTM A355-89 (2012)	A	K24065	---	0.38–0.43	0.50–0.70	0.15–0.35	0.035	0.040	1.40–1.80	---	0.30–0.40	Al 0.95–1.30
EN 10085:2001	32CrAlMo7-10	---	1.8505	0.28–0.35	0.40–0.70	0.40	0.025	0.035	1.50–1.80	---	0.20–0.40	Al 0.80–1.20
	34CrAlMo5-10	---	1.8507	0.30–0.37	0.40–0.70	0.40	0.025	0.035	1.00–1.30	---	0.15–0.25	Al 0.80–1.20
	34CrAlNi7-10	---	1.8550	0.30–0.37	0.40–0.70	0.40	0.025	0.035	1.50–1.80	0.85–1.15	0.15–0.25	Al 0.80–1.20
	41CrAlMo7-10	---	1.8509	0.38–0.45	0.40–0.70	0.40	0.025	0.035	1.50–1.80	---	0.20–0.35	Al 0.80–1.20
GB/T 3077-1999	Grade 38CrMoAl	---	---	0.35–0.42	0.30–0.60	0.20–0.45	0.035	0.035	1.35–1.65	0.30	0.15–0.25	Al 0.70–1.10; Cu 0.30
GB/T 3078-94	Grade 38CrMoAlA	---	---	0.35–0.42	0.30–0.60	0.20–0.45	0.025	0.025	1.35–1.65	0.30	0.15–0.25	Al 0.70–1.10; Cu 0.25
ISO 683-10:1987	41 CrAlMo 7 4	---	---	0.38–0.45	0.50–0.80	0.50	0.030	0.035	1.50–1.80	---	0.25–0.40	Al 0.8–1.20
JIS G4053:2008	Symbol SACM 645	---	---	0.40–0.50	0.60	0.15–0.50	0.030	0.030	1.30–1.70	0.25	0.15–0.30	Al 0.70–1.20; Cu 0.30

Table 1.4 List of Comparative Cr-Ni-Mo Wrought Austenitic Stainless Steels

Specification	Designation	UNS No.	Steel No.	Weight, %, max, Unless Otherwise Specified								
				C	Mn	Si	P	S	Cr	Ni	Mo	Others
ASME SA-240/SA-240M	Type 317L	S31703	---	0.030	2.00	0.75	0.045	0.030	18.0–20.0	11.0–15.0	3.0–4.0	N 0.10
ASTM A240/A240M-15a	Type 317L	S31703	---	0.030	2.00	0.75	0.045	0.030	18.0–20.0	11.0–15.0	3.0–4.0	N 0.10
EN 10028-7:2007	X2CrNiMo18-15-4	---	1.4438	0.030	2.00	1.00	0.045	0.015	17.5–19.5	13.0–16.0	3.0–4.0	N 0.10
EN 10088-2:2014	X2CrNiMo18-15-4	---	1.4438	0.030	2.00	1.00	0.045	0.015	17.5–19.5	13.0–16.0	3.0–4.0	N 0.10
GB 4237-92	Grade 00Cr19Ni13Mo3	---	---	0.030	2.00	1.00	0.035	0.030	18.00–20.00	11.00–15.00	3.00–4.00	---
GB 4239-91	Grade 00Cr19Ni13Mo3	---	---	0.030	2.00	1.00	0.035	0.030	18.00–20.00	11.00–15.00	3.00–4.00	---
ISO 9328-7:2004	Grade X2CrNiMo18-15-4	---	---	0.030	2.00	1.00	0.045	0.015	17.5–19.5	13.0–16.0	3.00–4.0	N 0.11
JIS G 4304:2012	Symbol SUS317L	---	---	0.030	2.00	1.00	0.045	0.030	18.00–20.00	11.00–15.00	3.00–4.00	---
JIS G 4305:2012	Symbol SUS317L	---	---	0.030	2.00	1.00	0.045	0.030	18.00–20.00	11.00–15.00	3.00–4.00	---
SAE J405 JUN98	Type 317L	S31703	---	0.030	2.00	0.75	0.045	0.030	18.00–20.00	11.00–15.00	3.00–4.00	N 0.10

related manufacturing processes (including heat treatment), and so forth, a methodology had to be put in place and rules had to be established. However, as much as methodology and rules were essential in preparing this handbook, there were many instances where they would not cover every variable and circumstance. Therefore, difficult comparison decisions—such as those described previously—had to be made. There were literally hundreds, if not more than a thousand, such decisions made in this handbook. In these cases, the closest match comparison decisions were made at the discretion of the editor.

Organization

Two of the main variables in selecting a specific grade of steel are its intended application (use) and product form, which usually narrows the selection to a family of steels. Therefore, the remaining data chapters in this handbook were organized by product form and use, as follows.

<u>Chapter No.</u>	<u>Title</u>
2.	Carbon and Alloy Steels for General Use
3.	Structural Steel Plates
4.	Pressure Vessel Steel Plates
5.	Steel Tubes and Pipes
6.	Steel Forgings
7.	Steel Castings
8.	Wrought Stainless Steels
9.	Steels for Special Use

Although this list of chapter titles, at first glance, looks rather straightforward, there were difficult decisions regarding the steel comparisons within each chapter. For example, ASTM has 9 definitions for *pipe* and 22 definitions for *tube*, depending on the standard's subject matter and application (see *ASTM Dictionary of Engineering Science & Technology*, 10th edition). In contrast, ISO 2604, Steel Products for Pressure Purposes—Quality Requirements—Part II: Wrought Seamless Tubes, notes that "The word *tube* is synonymous with *pipe*."

Each standard is typically listed only in one chapter, but there are exceptions. For example, ASTM A240/A240M–15a, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications, appears in more than one chapter due to its dual role for pressure vessel and general applications (i.e., Chapter 4—Pressure Vessel Steel Plates and Chapter 8—Wrought Stainless Steels). Similarly, the Japanese Industrial Standards (JIS) and Chinese (Guojia Biaozhun, or GB) stainless steel flat product standards were also included in Chapters 4 and 8.

Definitions of Steel Terms

It is common to find terminology standards for steels within most but not all standard development organizations (SDOs). These standards are very useful when working with steel standards, particularly when interpreting specific terms. Table 1.5 contains a list of steel terminology standards.

It is important to note that these standards differ in the terms used to describe the different types of steel. The user of comparative steel standards data must take into account that each national SDO has their own set of terms and definitions for steels and related products and, in some cases, may have multiple definitions. For example, three different definitions for carbon steel can be found in ASTM standards A941-13b, A902-14, and F1789-14a.

A summary of the chemical element limits for ASTM A941-13b alloy steel and EN 10020:2000 non-alloy steel is shown in Table 1.6. Although the limits seem to be the same, it is important to note the 70 % rule in EN 10020, Paragraph 3.1.2, which states:

> Where for elements other than manganese a maximum value only is specified in the product standard or specification for the ladle analysis, a value of 70 % of this maximum value shall be taken for classification as set out in tables 1 and 2. For manganese see note *a* of table 1.

In some cases, this 70 % rule resulted in several steels being noncomparable. For example, EN 10028–3:2009, Flat Products Made of Steels for Pressure Purposes—Part 3: Weldable Fine Grain Steels, Normalized, contains steels with a nickel content of 0.50 % maximum (i.e., there is no minimum nickel requirement). Using the 70 % rule, this would define these steels to contain 0.35 % Ni, which is over the 0.30 % maximum limit for non-alloy steels (carbon steels), thereby making them alloy steels and thus becoming noncomparable with non-alloy steels.

ASTM A941-13b and EN 10020:2000 share the same definition for stainless steel, as follows.

> Stainless steel a steel that conforms to a specification that requires, by mass percent, a minimum chromium content of 10.5 or more, and a maximum carbon content of less than 1.20.

In this handbook, steels have been divided into three main categories:

1. Carbon Steels (Non Alloy Steels)
2. Alloy Steels
3. Stainless Steels

Table 1.5 List of Steel Terminology Standards

ASTM A941-13b	Standard Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys
ASTM A644-14	Standard Terminology Relating to Iron Castings
ASTM A751-14a	Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
ASTM A902-15	Standard Terminology Relating to Metallic Coated Steel Products
EN 10020:2000	Definition and Classification of Grades of Steel
EN 10027-1:2005	Designation systems for steels—Part 1: Steel names
EN 10052:1993	Vocabulary of Heat Treatment Terms for Ferrous Products
EN 10079:2007	Definition of Steel Products
EN 10169-1:2003	Continuously Organic Coated (Coil Coated) Steel Flat Products—Part 1: General Information (Definitions, Materials, Tolerances, Test Methods)
EN 10266:2003	Steel tubes, fittings and structural hollow sections—Symbols and definitions of terms for use in product standards
GB/T 13304-1991	Steels—Classification
GB/T 15574-1995	Steel products classification and definitions
GB/T 15575-1995	Steel products standard designation
GB/T 341-1989	Steel wire—Classification and vocabulary
JIS G 0201:2000	Glossary of terms used in iron and steel (Heat treatment)
JIS G 0202:2013	Glossary of terms used in iron and steel (Testing)
JIS G 0203:2009	Glossary of terms used in iron and steel (Products and quality)
ISO 6929:1987	Steel products—Definitions and classification
ISO 2532:1974	Steel wire ropes—Vocabulary
ISO 3252:2000	Powder metallurgy—Vocabulary
ISO 4885:1996	Ferrous products—heat treatments—Vocabulary
ISO 8954-1:1990	Ferroalloys—Vocabulary—Part 1: Materials
ISO 8954-2:1990	Ferroalloys—Vocabulary—Part 2: Sampling and sample preparation
ISO 8954-3:1990	Ferroalloys—Vocabulary—Part 3 Sieve analysis
ISO 17893:2004	Steel wire ropes—Vocabulary, designation, and classification

Table 1.6 Limits for EN 10020:2000 and ASTMA 941-13b Between Carbon Steels/Non-Alloy Steel and Alloy Steela (% by mass)

Symbol	Name	EN 10020:2000b	ASTM A941-13b
Al	Aluminum	0.30	0.30
B	Boron	0.0008	0.0008
Bi	Bismuth	0.10	---
Co	Cobalt	0.30	0.30
Cr	Chromium	0.30	0.30
Cu	Copper	0.40	0.40
La	Lanthanides	0.10	---
Mn	Manganese	1.65b	1.65
Mo	Molybdenum	0.08	0.08
Nb	Niobium	0.06	0.06
Ni	Nickel	0.30	0.30
Pb	Lead	0.40	0.40
Se	Selenium	0.10	---
Si	Silicon	0.60	0.60
Te	Tellurium	0.10	---
Ti	Titanium	0.05	0.05
V	Vanadium	0.10	0.10
W	Tungsten	0.30	0.30
Zr	Zirconium	0.05	0.05
	Other (except C, P, S, N)	0.10	0.10

[a]Alloy steel when equal to or greater than the limit.

[b]Where manganese is specified only as a maximum, the limit value is 1.80 % and the 70 % rule does not apply (see 3.1.2 of EN 10020:2000).

ASTM A941-13b and EN 10020:2000 were used as guidelines in developing these categories. Where practical, these steel categories were further divided into subcategories based on their product form, intended application, service requirement, or other similar criteria.

Cautionary Note

Many standard specifications include cautionary paragraphs that warn users about their responsibilities (e.g., see Paragraph 1.5 from ASTM A53/A53M-12, quoted here). Accordingly, it is the user's responsibility when comparing steel standards to perform an engineering review of each standard to ensure that it is suitable for their intended application.

> The following precautionary caveat pertains only to the test method portion, Sections 7, 8, 9, 13, 14, and 15 of this specification: This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.

Questions Regarding the Rules of Comparison

When comparing two or more steel standards, the following questions must be asked:

1. Should mechanical properties or chemical composition be the main criteria? If mechanical properties are compared, which property should be the first criteria for comparison, that is, yield strength, tensile strength, elongation, impact strength, hardness, and so on? Once having selected a primary criterion, say tensile strength, should there be a secondary criterion for ranking the comparative steels within this group, for example, yield strength, hardness, and so on? When mechanical properties or chemical compositions vary with section thickness for a given steel grade, which section thickness data should be selected as the criteria for comparison? When two steels have the same minimum tensile strength values but have different yield strength values, are they no longer similar?
2. Should comparisons be based on the data's minimum values, maximum values, or average values of their minimum/maximum ranges? Should alloy steels and stainless steels be compared based on their mechanical properties when they generally are selected for use based on their alloying elements' abilities to provide satisfactory service in their intended applications?
3. Is it reasonable to compare steels based only on their chemical compositions, regardless of their product form? That is, should forging steels be compared to steel plates or tubes because they have similar chemical compositions, and is this type of comparative data useful in engineering practice?

Noncomparable Steels

It is fundamental to understand that not all steels have comparative counterparts. Knowing that a steel is noncomparable can be just as important as knowing that there are comparative steels. Otherwise, valuable time could be wasted searching for something that does not exist.

Criteria for Comparing Steels

The two major criteria for comparing steels in this type of handbook are mechanical properties and chemical compositions. For each given standard steel grade, there is typically only one chemical composition, which makes it ideal as a comparison criterion. However, there are several mechanical properties that can be used to compare standard steel grades and, to be consistent throughout a handbook of this type, only one property can be chosen. The decision was to use a steel's tensile strength as the second comparison criterion.

Having settled on chemical composition and tensile strength as the two main comparison criteria, the next step was to decide when to apply one or the other, or both. Because carbon steels typically are selected based on mechanical properties, it was decided that tensile strength would be the first criterion used for comparing carbon steels. Likewise, because alloy steels and stainless steels generally are selected based on their chemistry, it was decided that chemical composition would be used to compare them. An exception to this methodology is made for the structural steels data in Chapter 3, where the tensile strength was used as the main comparison criterion for carbon and alloy steels. This exception was made because structural steels generally are selected based on their mechanical properties. Also in this same chapter, high-strength, low-alloy steels are treated as a subcategory to alloy steels, although ASTM A941 defines them separately.

Because there was insufficient space on a page to place both the chemical composition and mechanical properties tables, they were split into two separate tables. To assist the user in keeping track of the comparison criteria used for a given steel, each table within a chapter was sequentially numbered and appended with the letter A or B. Table numbers ending in the letter A designate that it was the main criterion used for comparison, whereas table numbers ending with the letter B were "mirrored" from the A tables. In this manner, the user must first consider the data in the A table, and then see how well the data in the B table match the steels that are being compared.

This is not a foolproof methodology of comparison. For example, ASTM A958 Grade SC 4330 has one chemical composition but has 13 different strength classes based on heat treatment (see Chapter 7). So just because two steel grades have comparative chemical compositions does not mean that they are comparable in mechanical properties and vice versa. Using data found in this handbook is only one step in finding suitable comparable steel for the intended application.

With this basic methodology in place, the following is a list of the comparison rules that were established to produce this handbook.

List of Comparison Rules

1. The first criterion of order for carbon (non alloy) steels is based on tensile strength, followed by yield strength; that is, if two steels have the same tensile strength, then they are placed in ascending order by yield strength, and if yield strength is not required, it is placed at the top of the order.
2. Typically, comparative groups are made for every 50 MPa (50 N/mm^2 or 7.25 ksi) in tensile strength (that is, a black line divides comparative groups every 50 Mpa [50 N/mm^2 or 7.25 ksi]). When an abundance of data is available, this limit may be reduced to improve the comparison accuracy.
3. Mechanical property subcategories, such as steels with impact testing below 20°C (4°F), are used to further narrow the comparison process.
4. If a carbon steel's tensile strength varies with section thickness, the tensile strength of the lowest section thickness will be used as the governing comparison factor. There is no technical reason for choosing the lowest section thickness; it is just that one had to be chosen.
5. If a carbon steel standard does not contain mechanical properties, such as those found in Chapter 2, Carbon and Alloy Steels for General Use, then the steels will be compared based on their carbon content.
6. The major criterion for alloy steel and stainless steel comparisons is chemical composition. Once these steels are placed in a comparative group by chemical composition, they are then arranged in ascending order within these groups by their tensile strength. Where possible, subcategories of alloy and stainless steel groups are made to further narrow the comparison process.
7. Chemical compositions listed are the heat analysis requirements in the standards (also called ladle or cast analysis). Product analyses are not listed.
8. The chemical composition and mechanical properties data for the same steel grades are typically not listed on the same page due to space limitations. Consequently, as a means of keeping the data consistent between these two sets of tables, each table is numbered, and each table number ends with either the letter A or B.
9. Each set of steel data in the tables is divided by two types of horizontal lines: black and gray. Black lines separate groups of steels that are more closely comparable to each other, whereas gray lines separate steel data within a comparative group. This does not mean that steels outside of these groups cannot be compared because these horizontal lines are dependent upon all of the comparison rules in this list and can be subjective at times. **Caution**: Do not confuse the thinner dividing black line within a table with the thicker black rule that borders the table. To assist in this regard, the pages were formatted to keep comparative groups together as much as practicable. However, when a group of comparative steels appears on more than one page, a note is placed at the bottom of the page to indicate that the comparative group continues on the following page ("Note: This group continues on the next page"). Likewise, when a specification within a group of comparative steels cannot fit onto just one page, a note is placed at the bottom of the page to indicate that the specification within the comparative group continues on the following page ("Note: This specification continues on the next page within the same group").
10. Steel data in standards are not always mandatory. Some data are listed as typical values or informative values or are found in supplementary requirements. This type of data is still very useful and has been included in this handbook whenever possible. This type of data is identified with an explanatory note that appears in the list of standards at the beginning of the related chapter.
11. Some standards included multiple requirements for impact testing, such as differing test temperatures or requirements for subsize specimens.

12. Where space permitted, as much data as possible were included. However, there are occasions when the phrase "see standard for impact test data" was used to indicate that more data could be found in the standard.
13. The phrase "see standard for impact test data" was also used when the standard did not specify a test temperature but did specify an absorbed energy value.
14. Impact testing values listed in the tables are typically for full-size specimens and for the minimum average result at the testing temperature but do not include the minimum individual test piece requirement, if any.
15. For the purpose of this handbook, phrases found in standards such as "may be applied if necessary" or "may be applied by agreement between the purchaser and supplier" or "the manufacturer may find it necessary to" or "when specified" or "may be added if necessary" are not a part of the comparison process.
16. Data from footnotes in the chemical composition and mechanical properties tables of steel standards were considered during the comparison process but were not always reported in the handbook due to lack of space in the tables or because they represented technical issues that were too complex to be represented in a tabular format. In these cases, the note "see standard" was used.
17. The same heat treatment terms used in each standard are listed at the beginning of each chapter. Abbreviations in the tables were made based on the terms used in the standards. A concerted effort was made to make the abbreviations consistent from chapter to chapter, although there are exceptions because each heat treatment abbreviation must be referred to in the list of heat treatment terms at the beginning of each chapter. There are many instances when the heat treatment requirements within a standard became very cumbersome to include in a small cell within a table. Consequently, the phrase "see standard" is used to direct the user to the standard to read all of the heat treatment details involved.
18. A determined effort was made to enter the data in this handbook in a manner identical to that listed in the related standard, including the use of niobium (Nb) or columbium (Cb). It should be noted that even within the same SDO, data were not always entered in the same manner from standard to standard; for example, TP304 versus TP 304, where a space between the letter P and the number 3 is listed in the data.

Brief Introduction to Steel Standards and Designation Systems

In the world of standardization, metals were at the forefront at the turn of the twentieth century. In 1895, the International Association for Testing Materials (IATM) held their first conference in Zurich and the standardization of metals began. The IATM encouraged members to form national chapters and, on June 16, 1898, 70 IATM members met in Philadelphia to form the American section of the International Association for Testing Materials, which in 1898 became the American Society for Testing Materials (ASTM).

By reviewing some examples of the more prominent metals' designation systems, a direction is offered to assist those who use metal standards as a part of their work or study. This section is not all-inclusive. The amount of information on this topic could easily make up a complete book.

ASTM Designation System

ASTM's designation system for metals consists of a letter (A for ferrous materials) followed by an arbitrary sequentially assigned number. These designations often apply to specific products; for example, A822 is applicable to seamless cold-drawn carbon steel tubing for hydraulic system service. Metric ASTM standards have a suffix letter M.

Examples of the ASTM ferrous metal designation system, describing its use of specification numbers and letters, are as follows:

ASTM A334/A334M-04a (2010), Grade 1—Pressure Vessel Plates, Alloy Steel and High-Strength Low-Alloy Steel, Quenched-and-Tempered:

- A describes a ferrous metal but does not subclassify it as cast iron, carbon steel, alloy steel, tool steel, or stainless steel.
- *334* is a sequential number without any relationship to the metal's properties.
- M indicates that the standard A334M is written in rationalized SI units (the "M" comes from the word "metric"); hence, together A334/A334M includes both inch pound and SI units.
- 04 indicates the year of adoption or last revision and a letter *a* following the year indicates the second revision of the standard in 2004.
- *(*2010)*,* a number in parentheses, indicates the year of last reapproval.
- Grade 1 indicates the type of steel.

In the steel industry, the terms *grade*, *type*, and *class* generally are defined as follows. *Grade* is used to describe chemical composition; *type* is used to define deoxidation practice; and *class* is used to indicate other characteristics such as strength level or surface finish. However, within ASTM standards, these terms were adapted for use to identify a particular metal within a metal standard and are used without any "strict" definition but essentially mean the same thing, although some loose rules do exist, as follows.

ASTM A106/A106M-14 Grade A, Grade B, Grade C—Seamless Carbon Steel Pipe for High-Temperature Service:

- Typically an increase in alphabet (such as the letters A, B, C) results in higher tensile or yield strength steels and, if it is an unalloyed carbon steel, an increase in carbon content.
- In this case: Grade A: 0.25 % C (max.), 48 ksi tensile strength (min.); Grade B: 0.30 % C (max.), 60 ksi tensile strength (min.); Grade C: 0.35 % C (max.), 70 ksi tensile strength (min.)

ASTM A276/A276M-15, Type 304, 316, 410—Stainless Steel Bars and Shapes:

- Types 304, 316, 410, and others are based on the SAE designation system for stainless steels (see SAE and former American Iron and Steel Institute [AISI] description that follows).

Another use of ASTM grade designators is found in pipe, tube, and forging products, where the first letter "P" refers to pipe, "T" refers to tube, "TP" may refer to tube or pipe, and "F" refers to forging. Examples are found in the following ASTM specifications:

- ASTM A335/A335M-15, Grade P22, Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service
- ASTM A213/A213M-15a, Grade T22, Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
- ASTM A312/A312M 15, Grade TP304, Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
- ASTM A336/A336M-10a, Grade F91, Alloy Steel Forgings for Pressure and High-Temperature Parts

ASTM Referenced Standards and Supplementary Requirements

ASTM standards contain a "referenced documents" section, which lists other ASTM standards that are referenced in the text and that either become a part of the original standard or its supplementary requirements. Supplementary requirements are listed at the end of the ASTM standards and do not apply unless specified in the purchase order—that is, they are optional.

SAE Designation System and Related AISI Designation System

For many years, certain grades of carbon and alloy steels have been designated by a four-digit AISI/SAE numbering system that identified the grades according to standard chemical compositions. Because the AISI does not write material specifications, the relationship between AISI and grade designations has been discontinued. Beginning with the 1995 edition of the Iron and Steel Society (ISS) Strip Steel Manual, the four-digit designations are referred to solely as SAE designations.

The SAE system uses a basic four-digit system to designate the chemical composition of carbon and alloy steels. Throughout the system, the last two digits give the carbon content in hundredths of a percent. Carbon steels are designated 10XX. For example, a carbon steel containing 0.45 % carbon is designated 1045 in this system.

Resulfurized carbon steels are designated within the series 11XX, resulfurized and rephosphorized carbon steels within 12XX, and steels having manganese contents between 0.9 % and 1.5 % but no other alloying elements are designated 15XX. Composition ranges for manganese and silicon and maximum percentages for sulfur and phosphorus are also specified.

For alloy steels, the first two digits of the SAE system describe the major alloying elements present in the material, the first digit giving the alloy group. For example the 43XX series of steels contain 1.65–2.00 % Ni, 0.50–0.80 % Cr, and 0.20–0.30 % Mo, along with composition ranges for manganese and silicon and the maximums for sulfur and phosphorus.

Additional letters added between the second and third digits include "B" when boron is added (between 0.0005 % and 0.003 %) for enhanced hardenability and "L" when lead is added (between 0.15 % and 0.35 %) for enhanced machinability. The prefix "M" is used to designate merchant quality steel (the least restrictive quality descriptor for hot-rolled steel bars used in noncritical parts of structures and machinery). The prefix "E" (electric-furnace steel) and the suffix "H" (hardenability requirements) are mainly

Table 1.7 Types and Identifying Elements in Standard SAE Carbon and Alloy Steels

Carbon Steels	Description
10XX	Non-resulfurized, 1.00 manganese maximum
11XX	Resulfurized
12XX	Rephosphorized and resulfurized
15XX	Non-resulfurized, over 1.00 manganese maximum
Alloy Steels	**Description**
13XX	1.75 manganese
40XX	0.20 or 0.25 molybdenum or 0.25 molybdenum and 0.042 sulfur
41XX	0.50, 0.80, or 0.95 chromium and 0.12, 0.20, or 0.30 molybdenum
43XX	1.83 nickel, 0.50 to 0.80 chromium, and 0.25 molybdenum
46XX	0.85 or 1.83 nickel and 0.20 or 0.25 molybdenum
47XX	1.05 nickel, 0.45 chromium, 0.20 or 0.35 molybdenum
48XX	3.50 nickel and 0.25 molybdenum
51XX	0.80, 0.88, 0.93, 0.95, or 1.00 chromium
51XXX	1.03 chromium
52XXX	1.45 chromium
61XX	0.60 or 0.95 chromium and 0.13 or 0.15 vanadium minimum
86XX	0.55 nickel, 0.50 chromium, and 0.20 molybdenum
87XX	0.55 nickel, 0.50 chromium, and 0.25 molybdenum
88XX	0.55 nickel, 0.50 chromium, and 0.35 molybdenum
92XX	2.00 silicon or 1.40 silicon and 0.70 chromium
50BXX	0.28 or 0.50 chromium
51BXX	0.80 chromium
81BXX	0.30 nickel, 0.45 chromium, and 0.12 molybdenum
94BXX	0.45 nickel, 0.40 chromium, and 0.12 molybdenum

applicable to alloy steels. The full series of classification groups is shown in Table 1.7.

UNS Designation System

The Unified Numbering System (UNS) is an alphanumeric designation system consisting of a letter followed by five numbers. This system represents only the chemical composition for an individual metal or alloy and is not a metal standard or specification. For the most part, existing systems such as the SAE designations were incorporated into the UNS so that some familiarity was given to the system where possible.

For example, the UNS prefix letter for carbon and alloy steels is "G," and the first four digits are the SAE designation; for example, SAE 1040 is UNS G10400. The intermediate letters "B" and "L" of the SAE system are replaced by making the fifth digit of the UNS designation 1 and 4, respectively, while the prefix letter "E" for electric furnace steels is designated in the UNS system by making the fifth digit "6." The SAE steels, which have a hardenability requirement indicated by the suffix letter "H," are designated by the Hxxxxx series in the UNS system. Carbon and alloy steels not referred to in the SAE system are categorized under the prefix letter "K."

Where possible, the first letter in the system denotes the metal group; for instance, "S" designates stainless steels. Of the five digits of the UNS designation for stainless steels, the first three are the SAE alloy classification; for example, S304XX. The final two digits are equivalent to the various modifications represented by suffix letters in the SAE system as given in the list of suffixes in Table 1.7. The UNS designations for ferrous metals and alloys are described in Table 1.8.

Canadian Standards Association (CSA)

The Canadian Standards Association (CSA) has established metal standards for structural steels (CSA G40.20/40.21), pipeline steels (CSA Z245.1), corrugated steel pipe (G401), wire products (CSA G4, G12, G30.x, G279.2, G387), sprayed metal coatings (G189), and welding consumables (CSA W48.x).

Most CSA material standards use SI units, although some are available in both SI and Imperial units (for example, CSA G40.20/G40.21-04). When a CSA standard designation is followed by the letter "M," it uses SI units, and if the letter "M" is not present, it may use both units or use only Imperial units. The type of measurement units adopted in CSA standards are specific industry driven, with some industries moving faster toward the exclusive use of SI units than others, and thus the reason for these differences.

As far as practicable, rationalization with relevant ISO standards has been achieved in CSA G4, Steel Wire Rope for General Purpose and for Mine Hoisting and for Mine Haulage. Similarly, the 2005 edition of CSA Z245.1, Steel Line Pipe, references requirements for ISO 1027:1998 (E) on radiographic image indicators for nondestructive testing: principles and identification, as well as ISO 5579:1998 on nondestructive testing—radiographic examination of metallic materials by X- and gamma rays—basic rules.

Introduction to European (EN) Standard Steel Designation System

The Comité Européen de Normalisation (CEN, the European Committee for Standardization) was founded in 1961 by the national standards bodies in the European Economic Community and European Free Trade Association (EFTA) countries. The CEN is a system of formal processes to produce standards, shared principally among:

- Thirty national members and the representative expertise they assemble from each country; these members vote for and implement European Standards (EN).
- Seven associate members and four affiliates.
- The CEN Management Centre, Brussels.

The CEN works closely with the European Committee for Electrotechnical Standardization (CENELEC), the European

Table 1.8 UNS Designations for Ferrous Metals and Alloys

UNS Descriptor	Ferrous Metals
Dxxxxx	Specified mechanical properties of steels
Fxxxxx	Cast irons
Gxxxxx	SAE and former AISI carbon and alloy steels (except tool steels)
Hxxxxx	AISI H-steels
Jxxxxx	Cast steels
Kxxxxx	Miscellaneous steels and ferrous alloys
Sxxxxx	Heat and corrosion-resistant (stainless) steels
Txxxxx	Tool steels
UNS Descriptor	**Welding Filler Metals**
Wxxxxx	Welding filler metals, covered and tubular electrodes classified by weld deposit composition

Telecommunications Standards Institute (ETSI), and the ISO. It also has close liaisons with European trade and professional organizations.

The principal task of CEN is to prepare and issue European standards (EN), defined as a set of technical specifications established and approved in collaboration with the parties concerned in the various member countries of CEN. They are established on the principle of consensus and are adopted by the votes of weighted majority. Adopted standards must be implemented in their entirety as national standards by each member country regardless of the way in which the national member voted, and any conflicting national standards must be withdrawn.

The identification of European standards in each member country begins with the reference letters of the country's national standards body—for example, BS for the British Standards Institution (BSI) in the United Kingdom; DIN for the German Institute for Standardization (Deutsches Institut für Normung); NF for the French national organization for standardization (Association Française de Normalisation, or AFNOR). It is followed by the initials EN and a sequential number of up to five digits. For example, BS EN 10025, DIN EN 10025, or NF EN 10025 are all the same EN standard, which is available in English, French, and German.

An EN standard may contain one document, or it may be made up of several parts. For example, EN 10028 Parts 1 through 7, where each part specifies a particular characteristic of the steel product, may not include the word *part* in the designation but rather it is replaced with a hyphen (e.g., EN 10028-1, etc.), meaning Part 1. The prefix "pr" preceding the EN designation identifies the document as a draft standard that has not yet been approved, (e.g., prEN 10088-1, etc.).

EN 10027 Standard Designation System for Steels

The CEN designation system for steels is standardized in EN 10027, which is published in two parts:

- Part 1—Steel Names
- Part 2—Numerical System

The steel name is a combination of letters and numbers as described by EN 10027-1. Within this system, steel names are classified into two groups. The system is similar in some respects to, but is not identical with, that outlined in an ISO technical report (ISO TS 4949:2003—Steel names based on letter symbols).

Steel Names

Steel Names Group 1, within EN 10027-1, refers to steels that are designated according to their application and mechanical or physical properties. These have names that are comprised of one or more letters related to the application, followed by a number related to properties. For example, the name for structural steels begins with the letter S, line pipe steels begin with the letter L, rail steels begin with the letter R, and steels for pressure purposes begin with the letter P, such as EN 10028-3 Steel Name P275NH.

Steel Names Group 2 is used for steels that are designated according to their chemical composition and are further divided into four subgroups, depending on alloy content. Examples of these Group 2 steel names are:

- EN 10222 2 Steel Name 13CrMo4 5
- EN 10250 4 Steel Name X2CrNi18 9

Numerical System

EN 10027-2 describes the system used for assigning steel numbers, which are complementary to the steel names described earlier. These consist of a fixed set of digits and hence are more suitable than the name for data processing purposes. The steel numbers are in the form 1.XXXX, where the "1" refers to steel. The first two digits following the "1" represent the steel group number. Examples of steel numbers are as follows:

- EN 10222 2 Steel Name 13CrMo4 5, Steel Number 1.7335
- EN 10250 4 Steel Name X2CrNi18 9, Steel Number 1.4307

Former National Standards Superseded by CEN Standards

An increasing number of national European and UK standards are being withdrawn and superseded by EN standards. This transition, from old to new standards, has made it increasingly difficult to compare the superseded national standards with current standards from other nations outside of Europe and the UK, let alone to compare them to the new EN standards. For example, if you are looking up a former national standard such as DIN 17441, it has been superseded by EN 10028-7:2007.

Superseded national standards may be replaced by more than one new EN standard, and some may have been partially replaced. So, a superseded national standard could be replaced by 2, 3, 4, or more new EN standards, or it may be only partially replaced by these new EN standards.

Indexes in this Handbook

One of the easiest ways of using this handbook is to refer to one of the four indexes. If a user is looking for a comparable steel, then the information can be found in at least one of the indexes, which are built around the steel designation systems described previously, namely:

- Steel Grade/Name Index
- UNS Number Index
- Steel Number Index
- Specification Designation Index