NICKEL ALLOY STEEL CASTINGS

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

Nº 406

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Location of Data

Nickel Alloy Steel Castings

INTRODUCTION

This bulletin presents data on the mechanical properties of nickel alloy steel castings. Many of the compositions used for castings are quite similar to those of standard wrought types. However, the mechanical properties of castings are not necessarily identical to those in wrought steels of corresponding composition because castings do not receive the benefits of hot working.

The mechanical properties shown in this bulletin were determined largely from standard specimens cut from separately cast 1-inch double keel bars of ASTM and/or AFS design using good foundry practice. The cases in which particular compositions are capable of meeting test-bar requirements in standard specifications are indicated, otherwise the data should be considered typical and not used for specification purposes.

Melting and casting practice from the foundry viewpoint are not covered in this bulletin. Such information can be found in several publications listed in the bibliography.[1, 2]

SPECIFICATIONS

In the standard specification systems, constructional steel castings usually are specified by mechanical properties with composition and heat treatment optional. Castings designed for more special applications, such as high or low temperatures, usually specify composition and heat treatment as well as mechanical properties. Standard specifications for cast alloy steels include:

American Society for Testing Materials

- A 128 Austenitic Manganese Steel Castings.
- A 148 High Strength Steel Castings for Structural Purposes.
- A 217 Alloy Steel Castings for Pressure-Containing Parts Suitable for High-Temperature Service.
- A 352 Ferritic Steel Castings for Pressure-Containing Parts Suitable for Low-Temperature Service.
- A 486 Steel Castings for Highway Bridges.
- A 487 Low Alloy Steel Castings Suitable for Pressure Service.
- A 488 Qualification of Procedures and Personnel for the Welding of Steel Castings.

American Society of Mechanical Engineers*

- SA-217 Specification for Alloy-Steel Castings for Pressure-Containing Parts Suitable for High-Temperature Service.
- SA-352 Specification for Ferritic Steel Castings for Pressure-Containing Parts Suitable for Low-Temperature Service.
- SA-487 Specification for Low-Alloy Steel Castings Suitable for Pressure Service.

Society of Automotive Engineers

- SAE J435a Automotive Steel Castings.

Government

- QQ-S-681 Steel, Cast.
- MIL-S-15083 (NAVY), Steel, Castings.
- MIL-S-10026 (ORD), Steel Castings (Centrifugal) for Gun Tubes.
- MIL-S-10029 (ORD), Steel Castings for Breech Rings.
- MIL-S-11356 (ORD), Steel Armor, Cast, Homogeneous Combat-Vehicle Type (¼ to 12 inches, inclusive).
- MIL-S-12253 (ORD), Steel Castings for Muzzle Brakes.
- MIL-S-23008 (SHIPS), Steel, Castings, Alloy, High Yield Strength (HY-80 and HY-100).
- MIL-S-46052 (MR), High Strength Low Alloy Steel Castings.

Association of American Railroads

- M-201 Steel Castings.

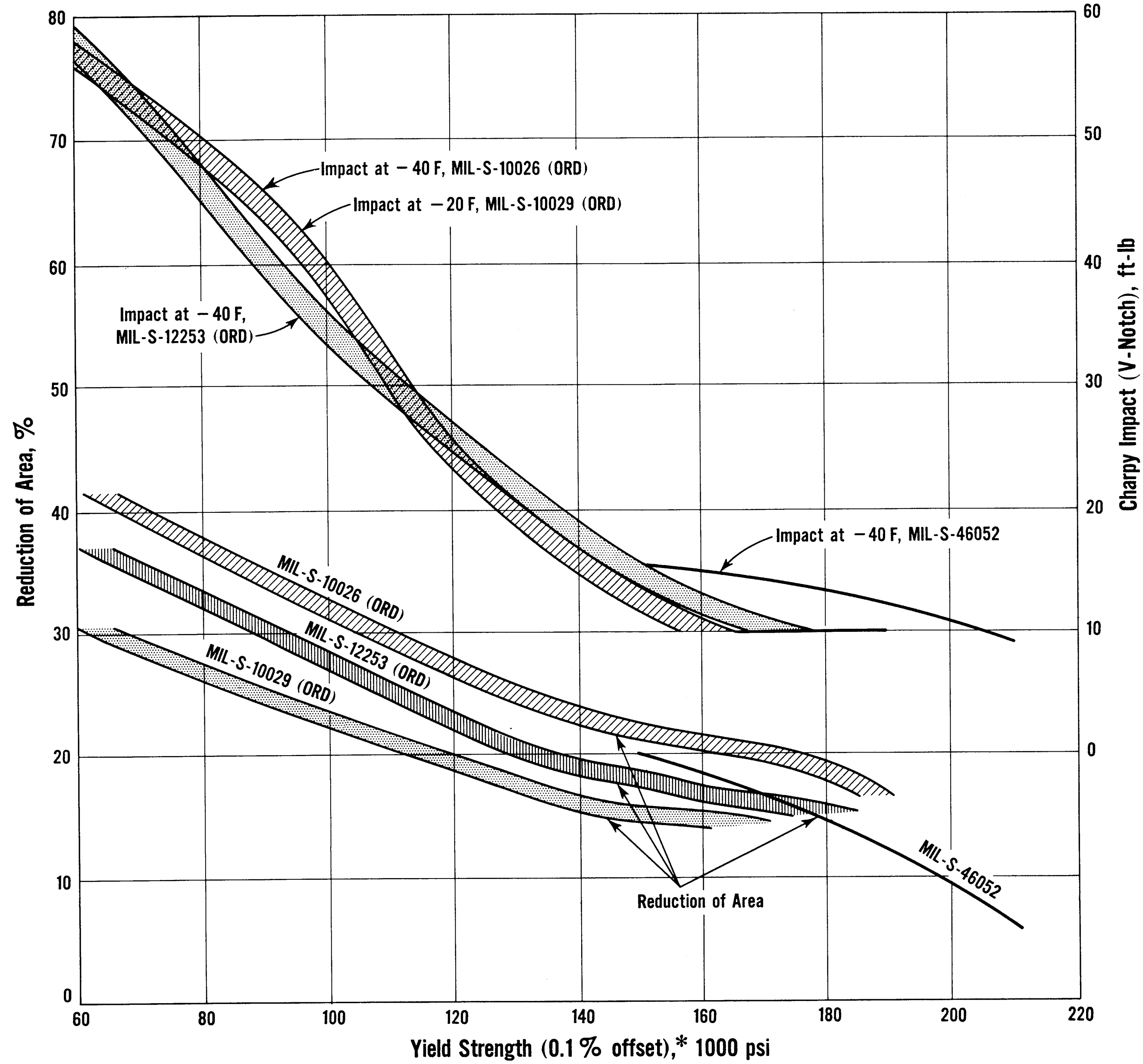
The basic tensile property requirements of the more general specifications (ASTM A 148, SAE J435a, QQ-S-681, MIL-S-15083 and AAR M-201) range from 80,000 to 175,000 psi minimum tensile strength. The remaining specifications cover more specific applications where properties such as toughness and ductility are also major requirements. For example, the minimum reduction of area and impact requirements, as related to ranges of yield strength, are shown in Figure 1 for four military specifications for ordnance components and high-strength alloy steel castings for general applications. The minimum impact requirements for homogeneous cast steel armor at various hardness ranges are shown in Figure 2.

* ASME numbers coincide with ASTM grades with identical technical requirements, except SA is used in place of A.

The specifications to which the various cast nickel alloy steels conform are listed in this buleltin in the tables and figures where typical properties are shown.

COMPOSITION AND HARDENABILITY

Although the compositions of cast steels do not follow exactly the ranges specified for the AISI-SAE standard wrought steels, they do fall into the same general alloy types and combinations. It is therefore customary and convenient to use the AISI-SAE numbers in referring to similar cast compositions. The effects of individual elements on hardenability are basically the same in cast and wrought steels. However, the cast form of a nominal AISI-SAE type may show slightly higher hardenability than the wrought form, because of the wider ranges permitted for the alloying elements and the larger grain size typical of the cast material. For example, in cast steels the manganese content, if not specified as an alloy, usually falls between 0.60 and 1.00 per cent. Generally silicon is between 0.35 and 0.65 per cent with a maximum of 0.80 per cent. It is also common for molybdenum, and sometimes nickel and chromium, ranges to be somewhat wider in cast than in wrought steels, as illustrated in Table I. Phosphorus and sulfur are specified usually at .05 and .06 per cent maximum, respectively.



*0.2% offset for MIL-S-46052

Fig. 1. Minimum reduction of area and impact requirements for various ranges of yield strength in four government specifications for steel castings. (See specifications for exact values.)

TABLE I

Composition of Cast and Wrought 4300 and 8600 Steels

Element	4300		8600	
	AISI-SAE Wrought (H Steel)	Cast[a] Steel	AISI-SAE Wrought (H Steel)	Cast[b] Steel
Manganese, %	0.55-0.90	0.60-1.00	0.70-1.05	1.00 max
Silicon, %	0.20-0.35	0.80 max	0.20-0.35	0.80 max
Nickel, %	1.55-2.00	1.40-2.00	0.35-0.75	0.40-0.80
Chromium, %	0.65-0.95	0.55-0.90	0.35-0.65	0.40-0.80
Molybdenum, %	0.20-0.30	0.20-0.40	0.15-0.25	0.15-0.30

[a] ASTM A 487, Class 10.
[b] ASTM A 487, Class 4.

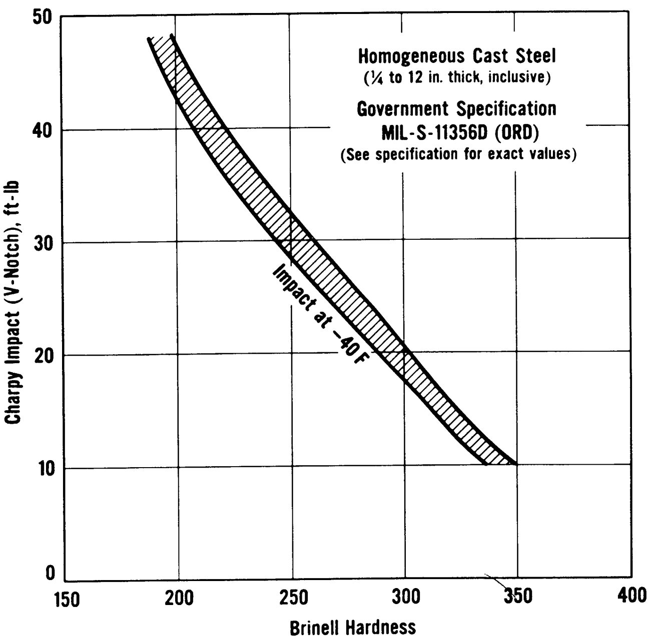


Fig. 2. Minimum impact requirements for armor of homogeneous cast steel for various hardness ranges.

HEAT TREATMENT

Alloy steel castings generally are supplied in the heat-treated condition. The usual types of heat treatment are: anneal (A), normalize (N), stress relieve (SR), normalize and temper (NT) and quench and temper (QT). In some instances a single grade may be tempered over a wide range of temperatures to obtain various combinations of strength and ductility.

MECHANICAL PROPERTIES

Mechanical properties of cast steels are specified on the basis of testing specimens cut from a standard keel bar (ASTM A 370) poured and heat treated simultaneously with the castings that they are to represent. When the hardenability of a steel composition is such that both keel bar and all sections of the casting respond to the heat treatment in the same way, the keel bar properties will predict the properties to be expected in the casting. However, keel bar properties do not necessarily represent casting properties when there is too great a difference in relative section sizes between casting and keel bar.

The majority of mechanical properties reported in this bulletin are based, as is customary, on properties developed in the standard 1 by 1¼ by 6-inch test bar. Broader relationships between composition, hardenability, section size and mechanical properties are outlined for wrought grades in several other Inco bulletins* which can be used as guides to indicate the properties of test bars and castings of different thicknesses. In addition, Tables XIII and XIV in this bulletin give qualitative indications of the section size capabilities of a number of the nickel steel compositions.

NICKEL STEELS

The steel casting compositions in which nickel is the principal alloying element have nickel contents up to 5.0 per cent. The range of typical carbon and nickel contents and representative mechanical properties for these casting grades are shown in Figure 3, along with the specifications to which they conform.[3, 4, 5]

The lower carbon, higher nickel steels provide tensile strengths in the 70,000-90,000 psi range along with excellent ductility, toughness and weldability. Castings of these compositions are employed extensively for truck frames in railroad and rapid transit rolling stock to secure weight reductions with safety. These steels are used also for carburized applications and heavy section castings, such as rock crusher frames, which are subject to severe shock loads and which may require repair by field welding.

Higher carbon 3.5 per cent nickel cast steels, approximating the AISI-SAE 2330 composition, develop tensile strengths from 80,000 to 100,000 psi, yet retain good ductility. The influence of carbon on the tensile properties of a normalized and tempered 3.5 per cent nickel steel is shown in Figure 4.[6] Six-inch sections of the 2330 type develop a tensile strength of 80,000 psi if normalized and tempered at 1200 F and 90,000 psi if liquid quenched and tempered at 1200 F.

The cast nickel steels are used in applications requiring resistance to the embrittling effects of low temperature, and further comments on low-temperature properties are given on page 15.

*Bulletin 6-A, "Hardenability of Nickel Alloy Steels."
Bulletin 6-B, "Isothermal Transformation Diagrams of Nickel Alloy Steels."
Bulletin 2-A, "Quenched and Tempered Nickel Alloy Steels."
Bulletin 2-C, "Annealed, Hot Rolled and Normalized Nickel Alloy Steels."

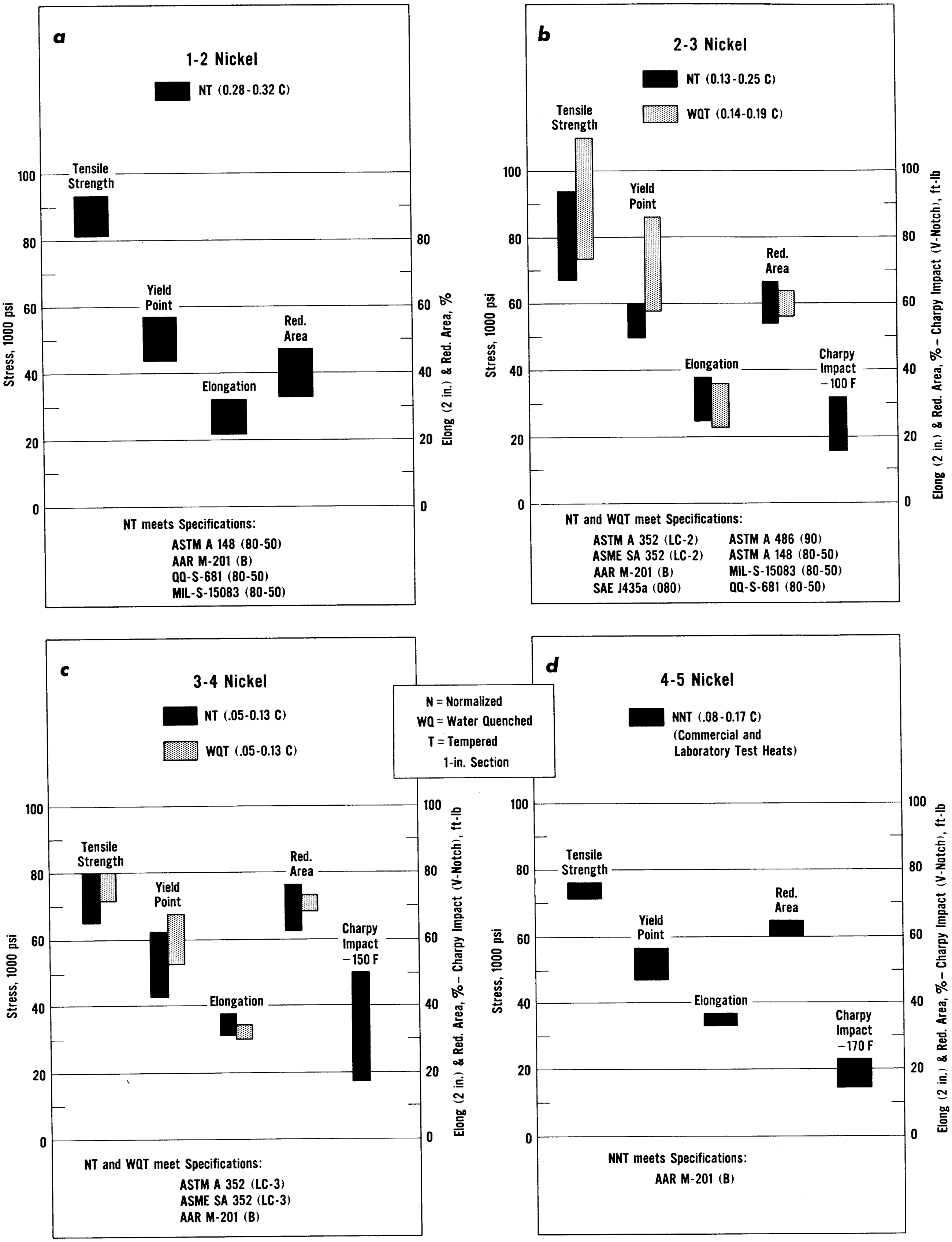


Fig. 3. Cast nickel steels: (1) Range of composition and properties and (2) Applicable specifications.[3-5]

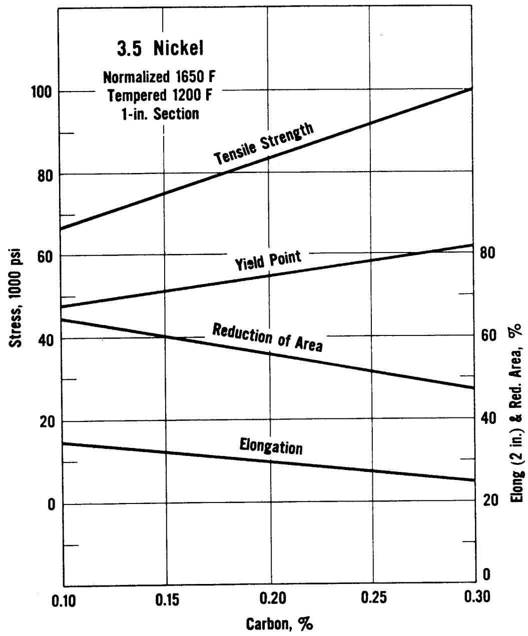


Fig. 4. Influence of carbon content on tensile properties of normalized and tempered cast 3.5 nickel (2300) steel.[6]

NICKEL-CHROMIUM STEELS

Nickel and chromium were among the earliest combinations of alloying elements used to achieve high strengths in cast steels, although they have not been as popular as the nickel-chromium-molybdenum triple alloy grades in recent years.

Figures 5 and 6 show that 1-inch sections of the 1.5 nickel-0.7 chromium (3100) composition at 0.30 to 0.40 per cent carbon achieve tensile strengths from 95,000 to 140,000 psi, depending upon heat treatment. Specifications to which the steel conforms also are listed. Figure 6 illustrates the influence of tempering temperature on the mechanical properties of oil quenched cast 3140 type steel. In sections to three inches thick, normalizing or liquid quenching and tempering around 1150 F gives a tensile strength in the 3100 type of approximately 75,000 to 80,000 psi at 0.20 per cent carbon and 90,000 to 100,000 psi at 0.35 per cent carbon. Elongation is 20 per cent or higher at both carbon levels.[7]

The properties of steels with higher nickel and chromium levels are shown in Figure 7.

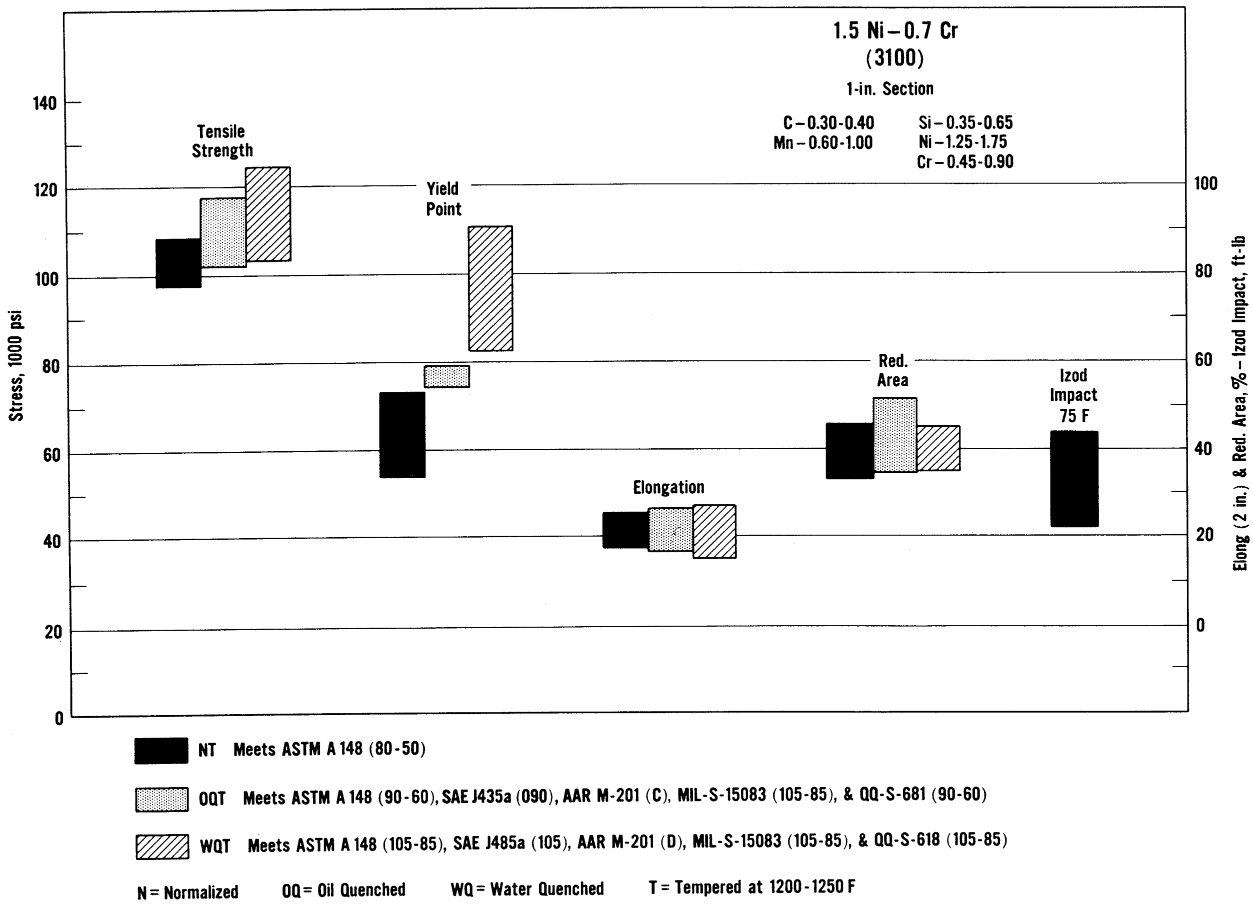


Fig. 5. Cast 1.5 nickel-0.7 chromium (3100) steel: (1) Range of composition and mechanical properties and (2) Applicable specifications.[4]

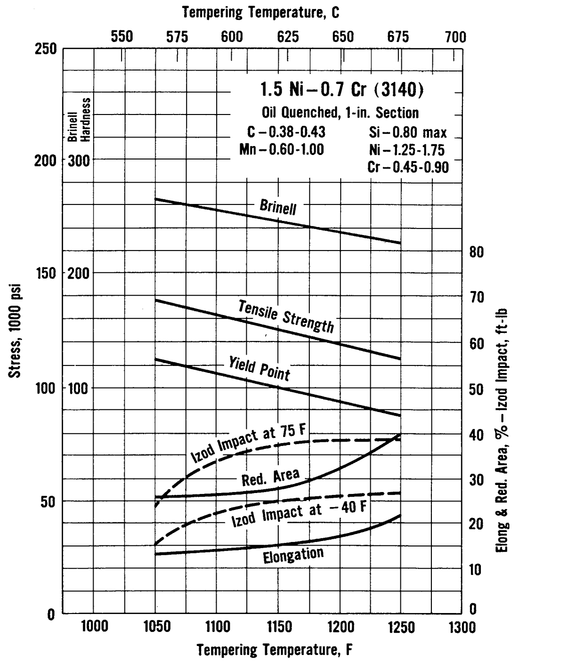


Fig. 6. Influence of tempering temperature on the mechanical properties of oil quenched 1.5 nickel-0.7 chromium (3140) cast steel.[6]

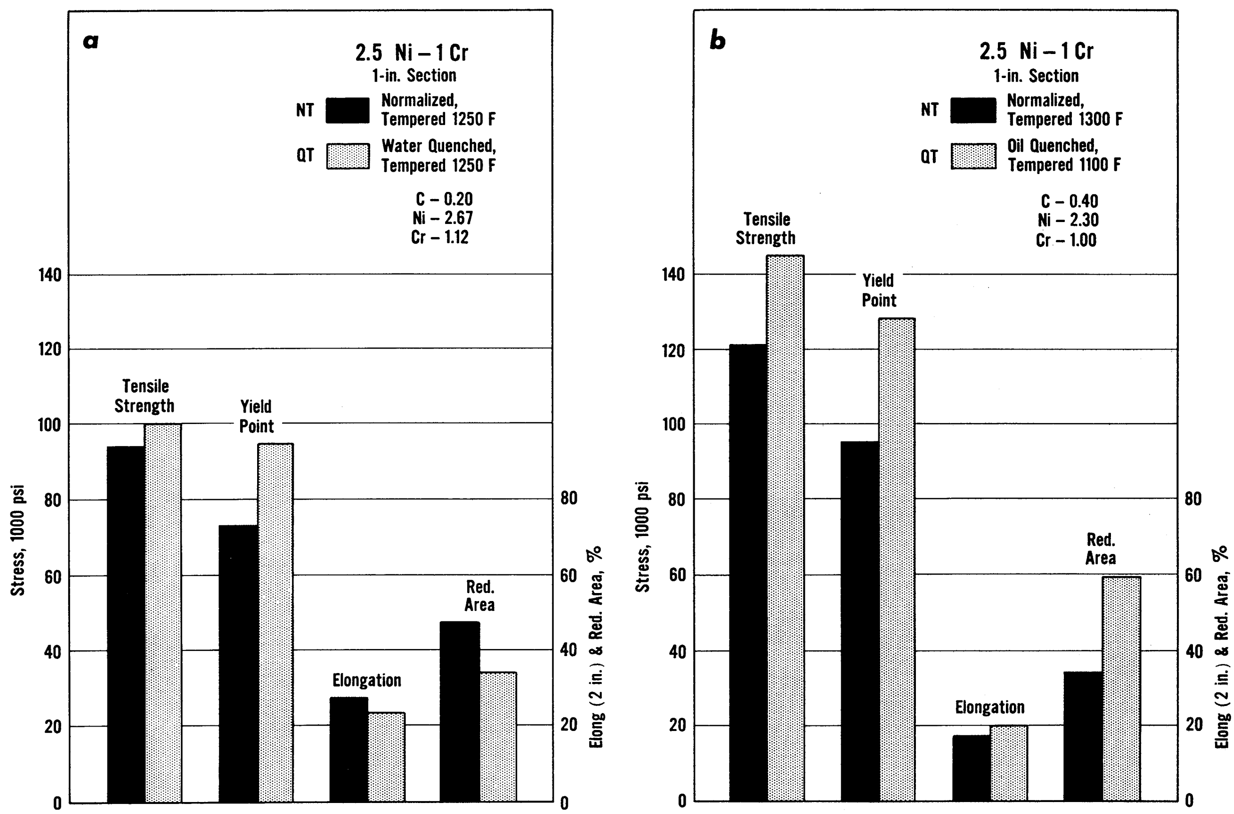
NICKEL-MOLYBDENUM STEELS

The nickel-molybdenum compositions, similar to the 4600 grade, have good strength and excellent ductility in the normalized and tempered and quenched and tempered conditions. The nominal composition range and mechanical properties are shown in Figure 8. This figure also shows the respective specifications to which the material conforms.[6, 8] This grade can be expected to develop tensile strengths around 110,000 to 120,000 psi in 3- to 4-inch sections of quenched and tempered castings.

The nickel-molybdenum steels are suited particularly for carburized applications and often are selected for castings requiring a hard, wear-resistant surface combined with a tough and ductile core.

NICKEL-CHROMIUM-MOLYBDENUM STEELS

The triple-alloy nickel-chromium-molybdenum compositions utilize the hardenability contributed by the individual alloying elements with maximum economy. By selecting the right alloy balance and heat treatment, they are able to offer a variety of strength-ductility-toughness combinations over a very wide range of casting sizes.

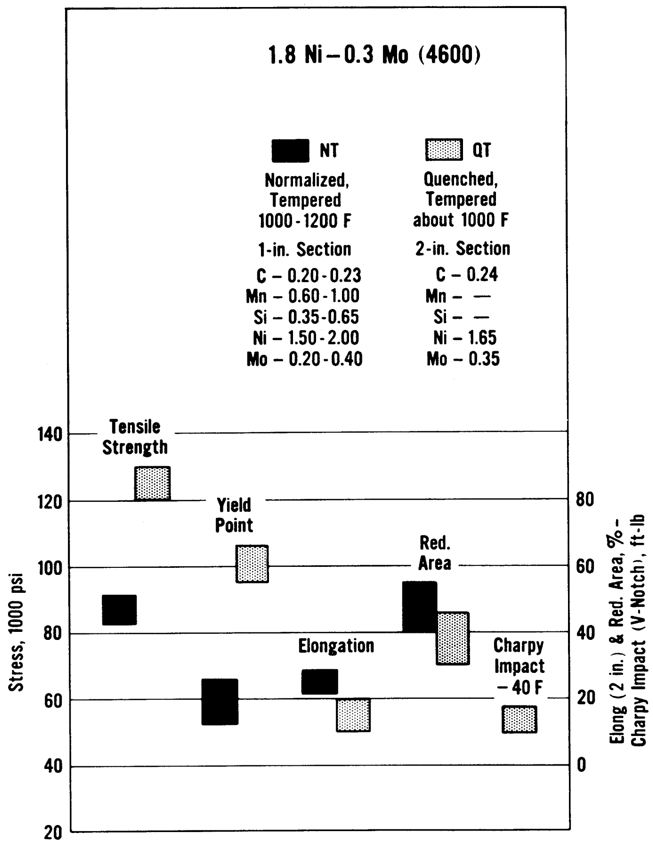


NT and QT meet Specifications:
ASTM A 148 (90-60)
SAE J435a (090)
MIL-S-15083 (90-60)
QQ-S-681 (90-60)

NT meets Specifications:
ASTM A 148 (105-85)
SAE J435a (0105)
MIL-S-15083 (105-85)
QQ-S-681 (105-85)

QT meets Specifications:
ASTM A 148 (120-95)
SAE J435a (0120)
MIL-S-15083 (120-95)
QQ-S-681 (120-95)

Fig. 7. Cast 2.5 nickel-1 chromium steels at two carbon levels: (1) Composition and tensile properties and (2) Applicable specifications.[4]



NT meets Specifications:	QT meets Specifications:
ASTM A 148 (80-50)	ASTM A 148 (120-95)
ASTM A 486 (70)	ASTM A 486 (120)
SAE J435a (080)	SAE J435a (0120)
MIL-S-15083 (80-50)	MIL-S-15083 (120-95)
QQ-S-681 (80-50)	QQ-S-681 (120-95)
AAR M-201 (C)	AAR M-201 (D)

Fig. 8. Cast 1.8 nickel-0.3 molybdenum (4600) steel: (1) Range of composition and mechanical properties and (2) Applicable specifications. NT specimens were cast statically, QT centrifugally.[6, 8]

0.6 Nickel-0.6 Chromium-0.22 Molybdenum (8600 Type)

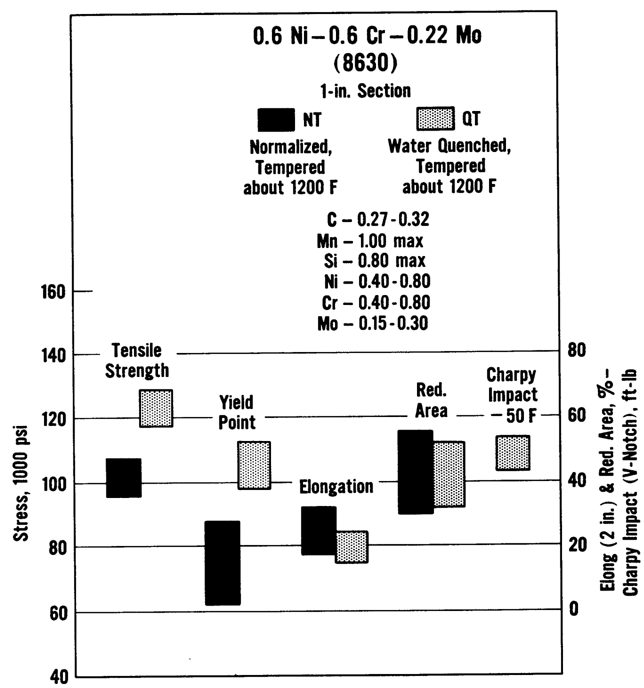
Figure 9 presents typical properties of the 8600 type heat treated by normalizing or quenching followed by tempering at about 1200 F.[5, 6, 8] Figure 10 is a chart of the properties after water quenching and tempering over the range 600 to 1300 F. The 8600 composition develops good combinations of strength and toughness. Castings at the 0.20 per cent level are used where weldability is a prime requirement, or where parts will be carburized to obtain wear-resisting surfaces. The 0.30 per cent carbon level is specified for parts where strength is a primary requirement. At the latter carbon level, 2-inch sections will develop a tensile strength of at least 95,000 psi if normalized and tempered at 1200 F and 105,000 if water quenched before a 1200 F temper.[10]

0.85 Nickel-0.6 Chromium-0.5 Molybdenum-.07 Vanadium-Copper-Boron

Table II shows the minimum properties required by ASTM A 487, Class 7Q, for this low-carbon 0.85 nickel-0.6 chromium-0.5 molybdenum-.07 vanadium-copper-boron steel. It meets the specified 100,000 psi yield strength and, when requested, 15 foot-pounds Charpy impact (V-notch) at –50 F. The specified properties can be developed in 2-inch cast sections water quenched from 1650-1750 F and tempered at 1100-1275 F.

1.8 Nickel-0.7 Chromium-0.3 Molybdenum (4300 Type)

The properties of the 4300 steel at 0.30 and 0.35 per cent carbon are presented in Figures 11, 12 and 13. Because of its high hardenability, the 4300 type is selected for medium- to heavy-section castings and for good combinations of strength and ductility in the normalized and tempered condition where liquid quenching is not feasible. At 0.35 per cent carbon, oil-quenched 4.5-inch sections develop 170,000 psi tensile strength if tempered at 800 F and 120,000 if tempered at 1200 F.



NT meets Specifications:	QT meets Specifications:
ASTM A 148 (90-60)	ASTM A 148 (120-95)
ASTM A 486 (90)	ASTM A 486 (120)
ASTM A 487 (4N)	ASTM A 487 (4Q)
ASME SA 487 (4N)	ASME SA 487 (4Q)
SAE J435a (090)	SAE J435a (0120)
MIL-S-15083 (90-60)	MIL-S-15083 (120-95)
QQ-S-681 (90-60)	QQ-S-681 (120-95)
AAR M-201 (C)	AAR M-201 (D)

Fig. 9. Cast 0.6 nickel-0.6 chromium-0.22 molybdenum (8630) steel: (1) Range of composition and mechanical properties and (2) Applicable specifications.[5, 6, 8]

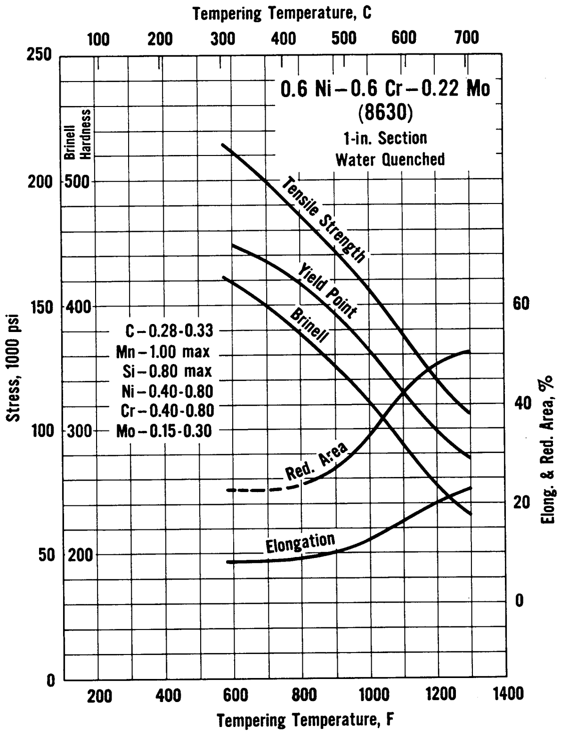
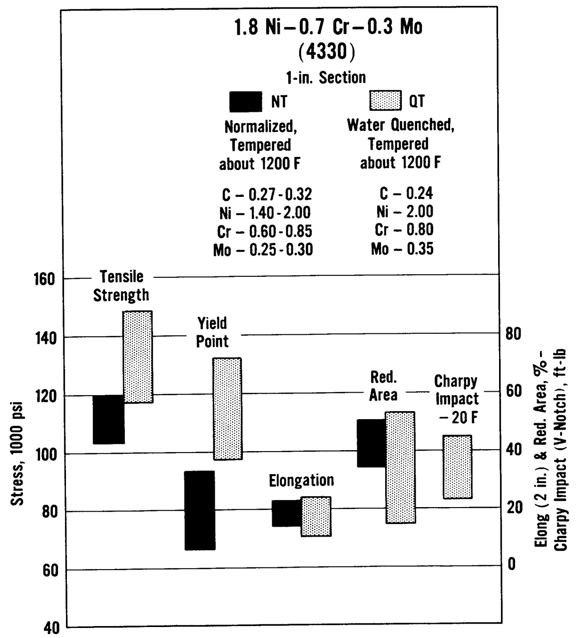


Fig. 10. Representative mechanical properties of cast 0.6 nickel-0.6 chromium-0.22 molybdenum (8630) steel.[4, 9]



NT meets Specifications:	QT meets Specifications:
ASTM A 148 (90-60)	ASTM A 148 (120-95)
ASTM A 487 (10N)	ASTM A 486 (120)
ASME SA 487 (10N)	ASTM A 487 (10Q)
MIL-S-15083 (90-60)	ASME SA 487 (10Q)
QQ-S-681 (90-60)	SAE J435a (0120)
SAE J435a (090)	MIL-S-15083 (120-95)
AAR M-201 (C)	QQ-S-681 (120-95)
	AAR M-201 (E)

Fig. 11. Cast 1.8 nickel-0.7 chromium-0.3 molybdenum (4330) steel: (1) Range of composition and mechanical properties and (2) Applicable specifications.[5, 6, 8]

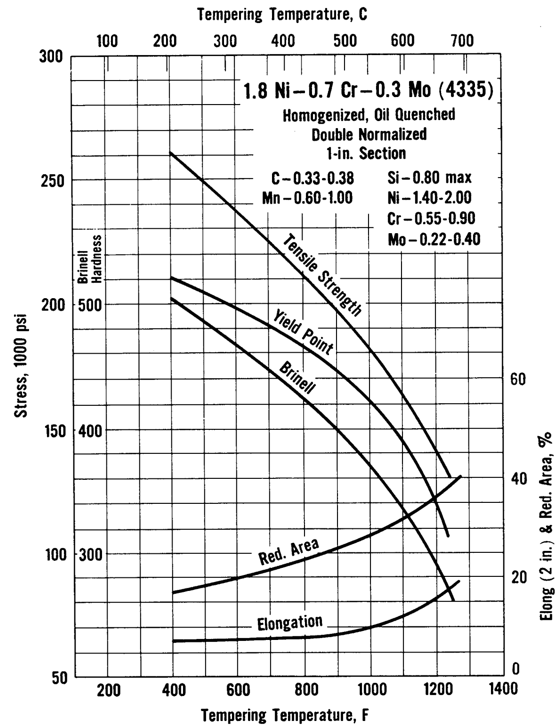


Fig. 12. Influence of tempering temperature on the tensile properties of cast 1.8 nickel-0.7 chromium-0.3 molybdenum (4335) steel.[6, 11]

TABLE II

Composition and Mechanical Properties of a Cast 0.85 Nickel-0.6 Chromium-0.5 Molybdenum-.07 Vanadium-Copper-Boron Steel for 100,000 psi Minimum Yield Point in Quenched and Tempered Condition

STEEL	
Type	0.85 Ni-0.6 Cr-0.5 Mo-.07 V-Cu-B
Specification	ASTM A 487, Class 7Q[a]
COMPOSITION	
Carbon, %	0.20 max
Manganese, %	0.60-1.00
Phosphorus, %	.04 max
Sulfur, %	.05 max
Silicon, %	0.80 max
Nickel, %	0.70-1.00
Chromium, %	0.40-0.80
Molybdenum, %	0.40-0.60
Vanadium, %	.03-0.10
Copper, %	0.15-0.50
Boron, %	.002-.006
HEAT TREATMENT	Water quench, temper 1100 F min
MECHANICAL PROPERTIES	
Tensile Strength, min, psi	125,000
Yield Point, min, psi	100,000
Elongation, min, %	15
Reduction of Area, min, %	30
Charpy Impact (V-Notch), min, ft-lb	15[b] (–50 F)

[a] Minimum yield point is 100,000 psi.
[b] When specified. Average of 3 tests, none below 10 ft-lb.

For ultra high strength or for service conditions involving abrasion, carbon contents higher than 0.35 per cent are specified sometimes. Figure 13 indicates the high-strength properties that can be obtained in compositions with normal and high (1.6 per cent) silicon. The high silicon permits tempering up to 600 F to develop yield strengths on the order of 200,000 psi without the reduction in toughness usually associated with tempering lower silicon steels in the range 500 to 600 F. Other information on cast 4300 steels is available.[11, 12, 13]

2.4 Nickel-1.2 Chromium-0.3 Molybdenum

As shown in Figure 14 this steel offers yield strengths above 100,000 psi with intermediate toughness in the quenched and tempered condition. For example, typical properties of 175,000 psi yield point and 22 foot-pounds Charpy impact (V-notch) are indicated for 1-inch sections water quenched and tempered at 800 F.

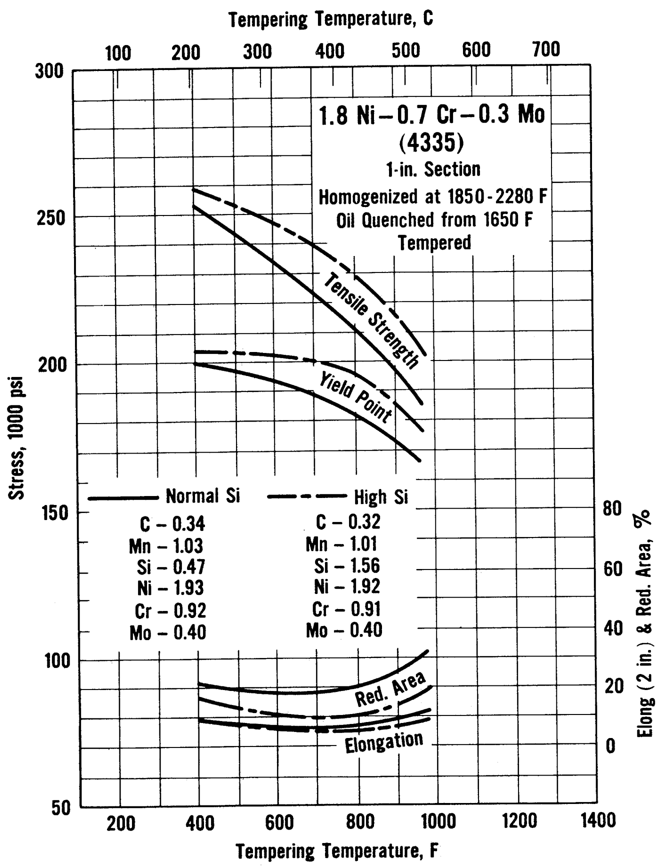


Fig. 13. Composition and tensile properties of cast 1.8 nickel-0.7 chromium-0.3 molybdenum (4335) steel with normal and high silicon.[11]

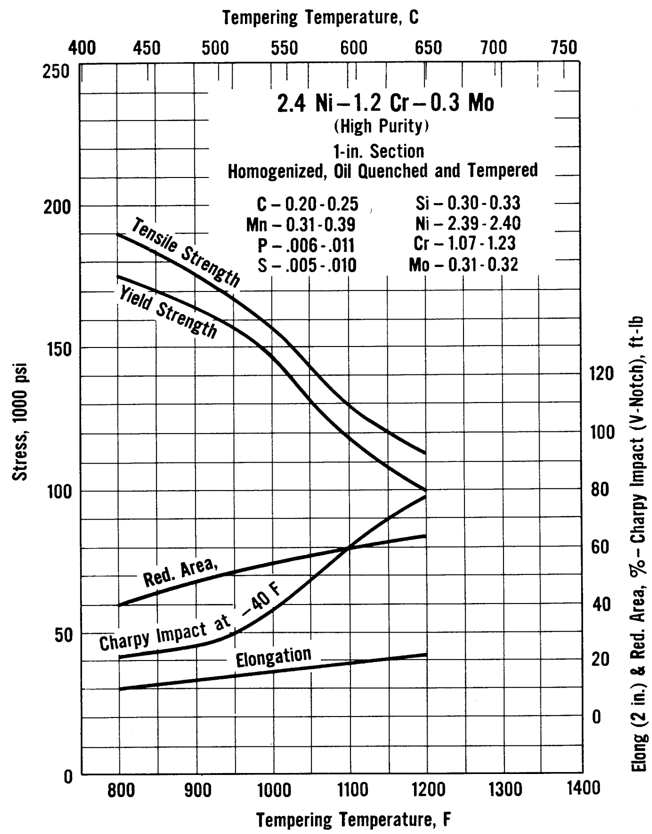


Fig. 14. Composition and mechanical properties of high-purity heats of cast 2.4 nickel-1.2 chromium-0.3 molybdenum steel.[14]

3 Nickel-1.5 Chromium-0.5 Molybdenum (HY-80) and HY-100 Types

Military requirements set forth in MIL-S-23008 (SHIPS) demand weldable steels developing strengths above 80,000 psi combined with exceptional resistance to shock and brittle fracture. Table III shows required properties and compositions. Figure 15 presents typical properties and composition within the low-carbon HY-80 specification range. The 80,000 psi grade (HY-80) is nominally, in per cent: 3.0 nickel, 1.5 chromium and 0.5 molybdenum, whereas the 100,000 psi grade (HY-100) is 3.2 nickel, 1.6 chromium and 0.5 molybdenum. The exceptional toughness of these grades is indicated by Charpy impact (V-notch) levels of 60 to 90 foot-pounds at −100 F, Figure 15. Nil ductility transition temperatures must be below −100 F, as shown in Table III. The steels are highly resistant to quench cracking and have excellent weldability because of their low-carbon contents. The properties in MIL-S-23008 (SHIPS) can be developed in 8-inch cast sections.

4 Nickel-2 Chromium-0.4 Molybdenum-0.1 Vanadium Air-Hardening Steel for Massive Sections

Table IV and Figure 16 show the composition and properties of this steel designed to develop a uniform bainitic structure and a minimum yield strength of 100,000 psi at 0.25-0.29 per cent carbon in 1- to 40-inch sections (or thicker) without the benefit of liquid quenching.[16] The data were developed from 3-inch thick castings normalized by controlled cooling at a rate simulating air cooling of a 40-inch section and tempered at 1150 F. Tests from an air-cooled casting with an 8-inch section were in close agreement.

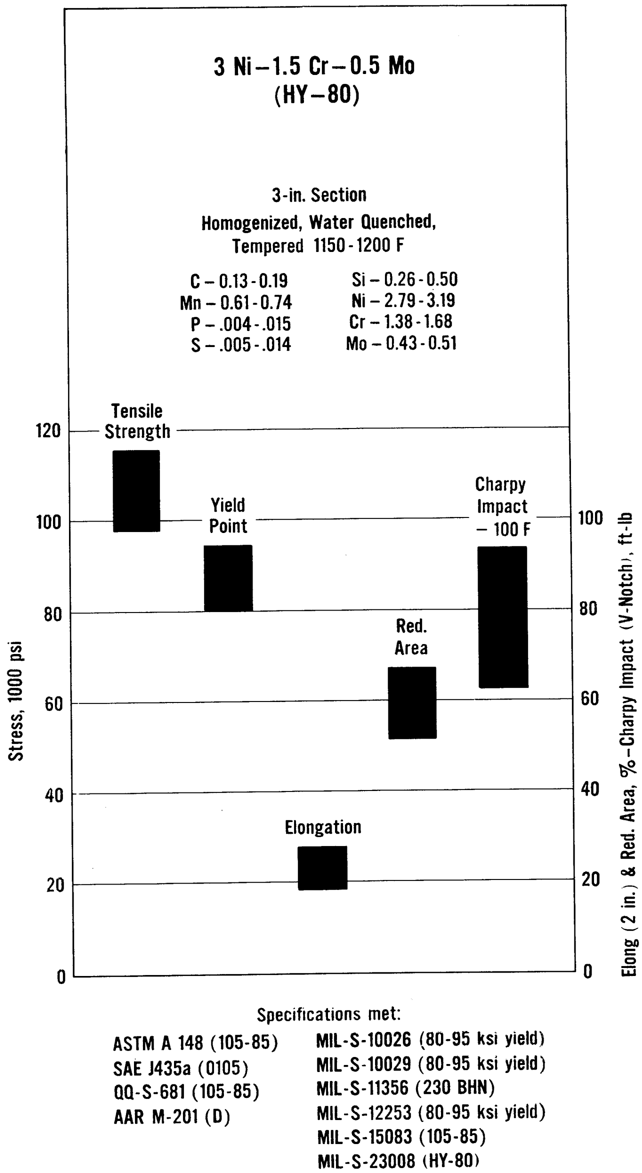


Fig. 15. Cast 3 nickel-1.5 chromium-0.5 molybdenum (HY-80) steel: (1) Range of composition and mechanical properties and (2) Applicable specifications.[14, 15]

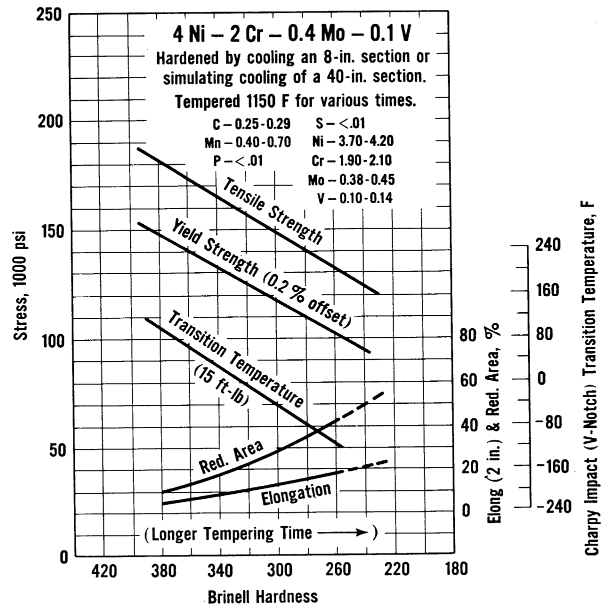


Fig. 16. Mechanical properties (laboratory data) of air hardening (bainitic) cast 4 nickel-2 chromium-0.4 molybdenum-0.1 vanadium steel developed for 100,000 psi minimum yield strength in massive sections.[16]

TABLE III

Specification Requirements for Composition and Mechanical Properties of Cast 3 Nickel-1.5 Chromium-0.5 Molybdenum (HY-80) and HY-100 Steels

STEEL		
Type	HY-80	HY-100
Specification	MIL-S-23008 (SHIPS)	MIL-S-23008 (SHIPS)
COMPOSITION		
Carbon, %	0.20 max	0.22 max
Manganese, %	0.55-0.75	0.55-0.75
Phosphorus, %	.020 max	.020 max
Sulfur, %	.015 max	.015 max
Silicon, %	0.50 max	0.50 max
Nickel, %	2.50-3.25	2.75-3.50
Chromium, %	1.35-1.65	1.35-1.85
Molybdenum, %	0.30-0.60	0.30-0.60
HEAT TREATMENT	Homogenize, normalize or anneal; quench and temper 1100 F min	Homogenize, normalize or anneal; quench and temper 1100 F min
MECHANICAL PROPERTIES		
Tensile Strength	Record[a]	Record[a]
Yield Strength (0.2% offset), psi	80,000-95,000	100,000-120,000
Elongation (2 in.), min, %	20	18
Charpy Impact (V-Notch) min, ft-lb	30 (–100 F)	30 (–100 F)
Nil Ductility Transition Temperature,[b] F	Below –100	Below –100

[a] To be recorded for information only.
[b] By the drop-weight test. This test shall govern if it conflicts with the Charpy impact data.

MANGANESE-NICKEL-CHROMIUM-MOLYBDENUM STEELS

High manganese (1.5 per cent) compositions similar to type 9500 and modifications are produced with nominal nickel levels of 0.6 or 1.2 per cent. Such steels have good hardenability for medium-section castings. For example, 4-inch sections of the 9530 type develop a tensile strength of about 110,000 psi if normalized and tempered at 1200 F and about 125,000 psi if water quenched before tempering.[10] Typical compositions, properties and specifications are shown in Figures 17 and 18.

NICKEL-MANGANESE STEELS

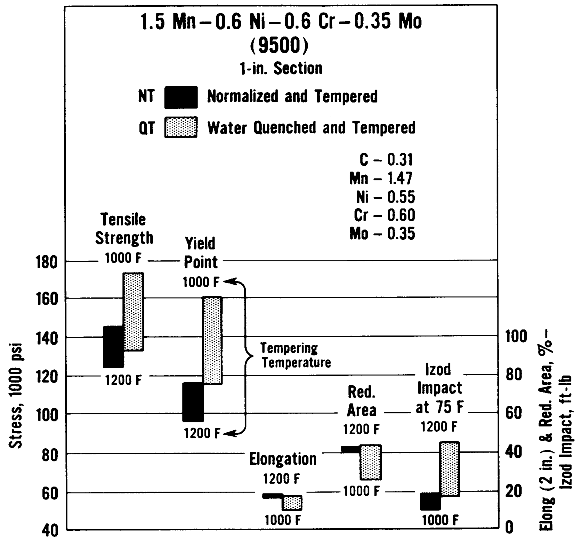
Figure 19 shows that the toughness of pearlitic manganese steels, widely used for castings in railroad, earth-moving and similar equipment, can be improved appreciably by adding nickel. The properties developed in 3-inch sections of normalized and tempered nickel-manganese steels are shown in Figure 20. A tensile strength of about 80,000 psi with good ductility can be expected in 6-inch sections of a 1.0 manganese-1.0 nickel steel at 0.22 per cent carbon after a 1600 F normalize and a 1100 to 1150 F temper.[7]

TABLE IV

Composition and Mechanical Properties of a Cast 4 Nickel-2 Chromium-0.4 Molybdenum-0.1 Vanadium Steel for Massive Sections up to at Least 40 Inches

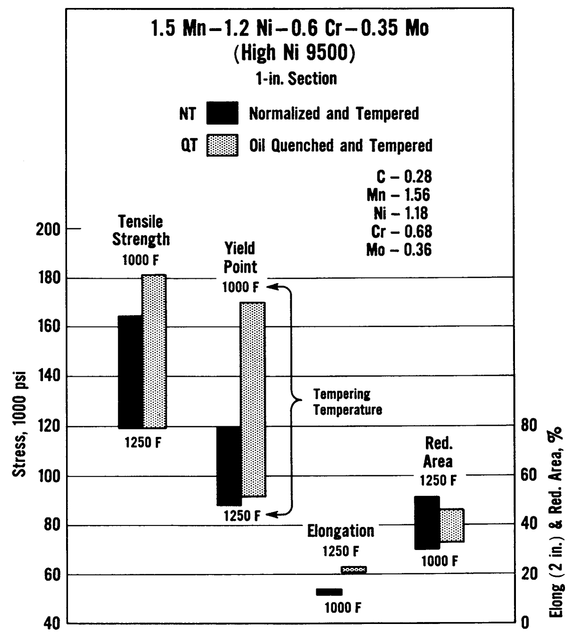
COMPOSITION	
Carbon, %	0.25-0.29
Manganese, %	0.40-0.70
Phosphorus, %	Less than .01
Sulfur, %	Less than .01
Silicon, %	0.20-0.40
Nickel, %	3.70-4.20
Chromium, %	1.90-2.10
Molybdenum, %	0.38-0.45
Vanadium, %	0.10-0.14
HEAT TREATMENT	Homogenize 1750-1950 F, normalize 1500 F, double temper 1150 F
MECHANICAL PROPERTIES[a]	
Tensile Strength, min, psi	125,000
Yield Strength (0.2% offset), min, psi	100,000
Elongation, min, %	14
Reduction of Area, min, %	30
Charpy Impact (V-Notch), min, ft-lb	15 (−70 F)
Fracture Appearance Transition Temperature (FATT, 50%), max, F	0

[a] Tests made on cast 3-inch bar heat treated to simulate the cooling rate of a 40-inch section.



NT meets Specifications:	QT meets Specifications:
ASTM A 148 (105-85)	ASTM A 148 (120-95)
ASTM A 487 (6N)	ASTM A 486 (120)
ASME SA 487 (6N)	ASTM A 487 (6Q)
SAE J435a (0105)	ASME SA 487 (6Q)
AAR M-201 (D)	SAE J435a (0120)
QQ-S-681 (105-85)	AAR M-201 (E)
MIL-S-15083 (105-85)	QQ-S-681 (120-95)
	MIL-S-15083 (120-95)

Fig. 17. Cast 1.5 manganese-0.6 nickel-0.6 chromium-0.35 molybdenum (9500) steel: (1) Composition and mechanical properties and (2) Applicable specifications.[4]



NT meets Specifications:	QT meets Specifications:
ASTM A 148 (105-85)	ASTM A 148 (120-95)
SAE J435a (0105)	ASTM A 486 (120)
AAR M-201 (D)	SAE J435a (0120)
QQ-S-681 (105-85)	AAR M-201 (E)
MIL-S-15083 (105-85)	QQ-S-681 (120-95)
	MIL-S-15083 (120-95)

Fig. 18. Cast 1.5 manganese-1.2 nickel-0.6 chromium-0.35 molybdenum (High nickel 9500) steel: (1) Composition and tensile properties and (2) Applicable specifications.[4]

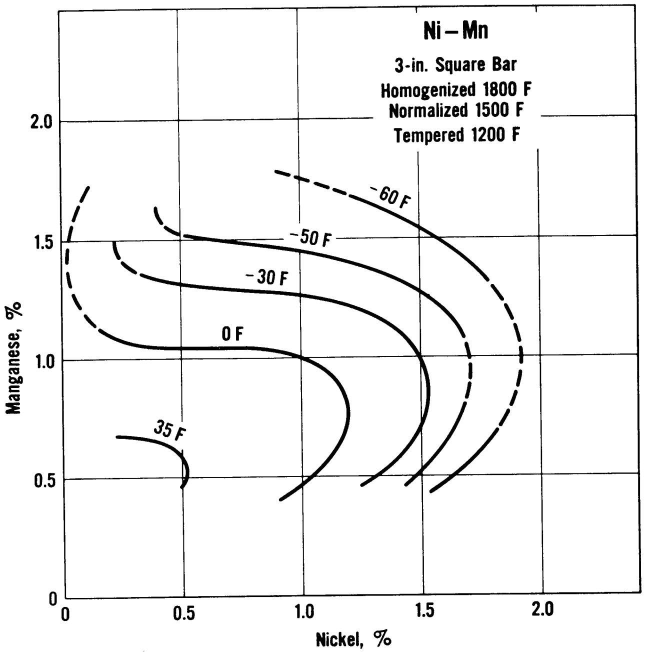


Fig. 19. Effect of nickel and manganese on the Charpy V-notch, 15 foot-pound transition temperature of cast steels containing 0.3 per cent carbon.[17]

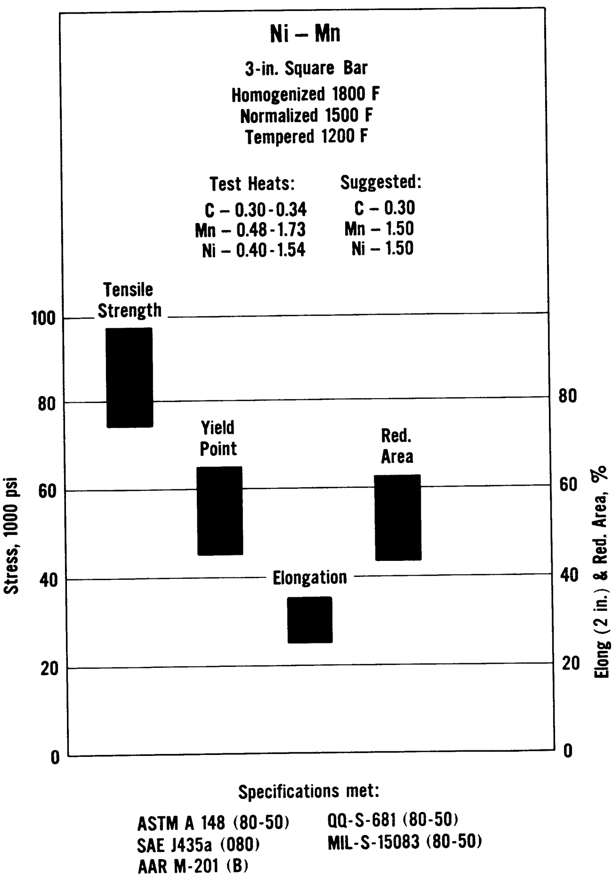


Fig. 20. Cast nickel-manganese steels (laboratory heats and data): (1) Composition and tensile properties and (2) Applicable specifications.[17]

NICKEL-VANADIUM STEELS

Nickel cast steels containing vanadium have strengths and ductilities somewhat higher than plain nickel compositions. Figure 21 presents typical properties for 1-inch sections of a 1.6 nickel-0.10 vanadium grade and can be compared with Figure 3a. In 2-inch sections a tensile strength of 90,000 psi and a yield strength of 60,000 psi can be expected when normalized and tempered in the range 1100 to 1200 F.

NICKEL STEELS FOR LOW-TEMPERATURE SERVICE

Low-carbon cast 2-3 and 3-4 per cent nickel steels are permitted under code regulations in equipment operating down to –100 F and –150 F, respectively, as covered by two specifications: ASTM A 352 and ASME SA 352. The specified requirements on composition, heat treatment and mechanical properties are assembled in Table V. Figures 3b and 3c show that the respective specification requirements are met by these nickel steels.

For temperatures moderately lower than –150 F, a 4-5 per cent nickel grade has been used successfully for the handling of liquid ethylene. Figure 3d shows about 22 foot-pounds Charpy V-notch impact at –170 F for this nickel range.

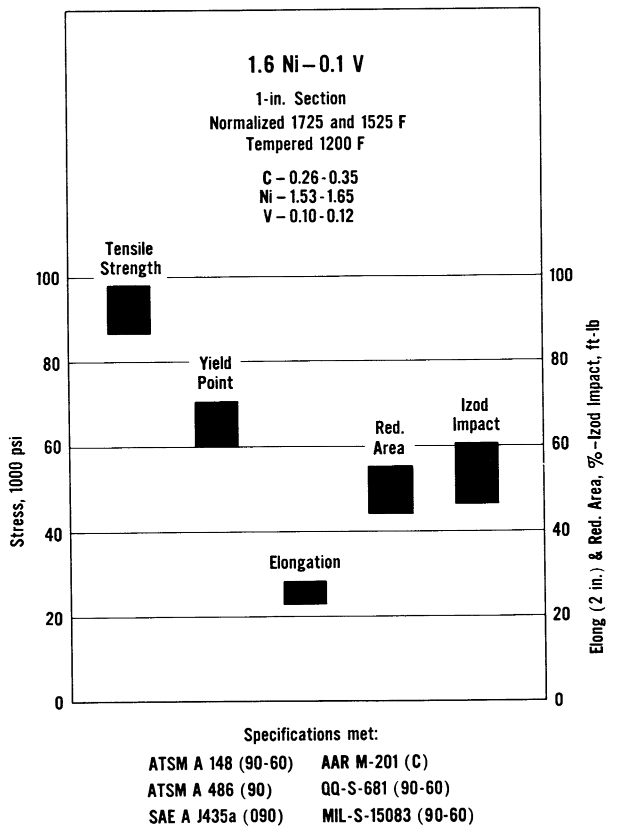


Fig. 21. Cast 1.6 nickel-0.1 vanadium steels: (1) Composition and mechanical properties and (2) Applicable specifications.[4]

TABLE V

Composition and Mechanical Properties of Cast Nickel Steels for Low-Temperature Service

STEEL		
Type	2-3 Nickel	3-4 Nickel
Specification	ASTM A 352 or ASME SA 352 Class LC2	ASTM A 352 or ASME SA 352 Class LC3
COMPOSITION		
Carbon, %	0.25 max	0.15 max
Manganese, %	0.50-0.80	0.50-0.80
Phosphorus, %	.05 max	.05 max
Sulfur, %	.05 max	.05 max
Silicon, %	0.60 max	0.60 max
Nickel, %	2.0-3.0	3.0-4.0
HEAT TREATMENT	Normalize or normalize and temper	Normalize or normalize and temper
MECHANICAL PROPERTIES		
Tensile Strength, min, psi	65,000	65,000
Yield Point, min, psi	40,000	40,000
Elongation (2 in.), min, %	24	24
Reduction of Area, min, %	35	35
Charpy Impact		
Keyhole Notch, min, ft-lb	15[a] (−100 F)	15[a] (−150 F)
V-Notch, min, ft-lb	20[b]	20[b]

[a] ASTM A 300 or ASME SA 300.
[b] ASME Boiler and Pressure Vessel Code, Case 1317-1. Test to be performed at the lowest service temperature.

NICKEL ALLOY STEELS FOR ELEVATED TEMPERATURE SERVICE

Cast steels generally have elevated temperature properties similar to wrought steels of comparable composition and heat treatment. The nickel-chromium-molybdenum steels offer attractive elevated temperature properties in combination with other useful characteristics. The ASME Boiler and Pressure Vessel Code has established the following maximum allowable design stresses: 6250 psi at 1000 F for Grade WC4 and 4000 psi at 1100 F for Grade WC5.

The tensile and creep properties for three nickel grades are given in Table VI. The steels correspond to the 4300 type and two compositions conforming to ASTM A 217, Grades WC4 and WC5 respectively. Another Inco bulletin contains more complete data on the elevated temperature properties of cast and wrought steels.*

NICKEL ALLOY STEELS FOR WEAR AND ABRASION RESISTANCE

Quenched and Tempered Nickel-Chromium-Molybdenum Types

Figure 22 gives an indication of the ability of cast nickel alloy steels to offer combinations of properties particularly required in wear and abrasion resisting

* Bulletin 4-D, "Elevated Temperature Properties of Nickel Alloy Steels."

TABLE VI

Creep and Tensile Properties of Three Grades of Cast Nickel-Chromium-Molybdenum Steel

Steel Grade[a]	Composition, %					Heat Treatment, F	Test Temperature, F	Stress (psi) for Designated Creep Rate of	
	C	Mn	Ni	Cr	Mo			.00001%/hr	.0001%/hr
4300	0.24-0.41	0.51-0.68	0.98-2.11	0.65-0.87	0.27-0.45	Normalized, tempered 1100-1300 F	500 800 900 1000	— — — —	60,000 40,000[b] 22,000[b] 7,000[b]
WC4[c]	0.20 max	0.50-0.80	0.70-1.10	0.50-0.80	0.45-0.65	Double normalized, tempered 1200-1300 F	900 950 1000	22,000 10,000 5,000	31,000 25,000 12,000
WC5[c]	0.20 max	0.40-0.70	0.60-1.00	0.50-0.90	0.90-1.20	Double normalized, tempered 1200-1300 F	1050 1100	7,000 4,000	— —

[a] At 75 F the mechanical properties of these steels are:

Grade	Tensile Strength, psi	Yield Point, psi	Elongation, %	Red. Area, %	Charpy Impact (V-Notch), ft-lb
4300	92,000-122,000	63,000-91,000	14-23	32-52	—
WC4	86,000	64,000	26	54	30
WC5	92,000	65,000	23	56	56

[b] This average was derived from several sets of tests which include some scatter because of differences in composition.[18]

[c] Grade in ASTM A 217.[1,6]

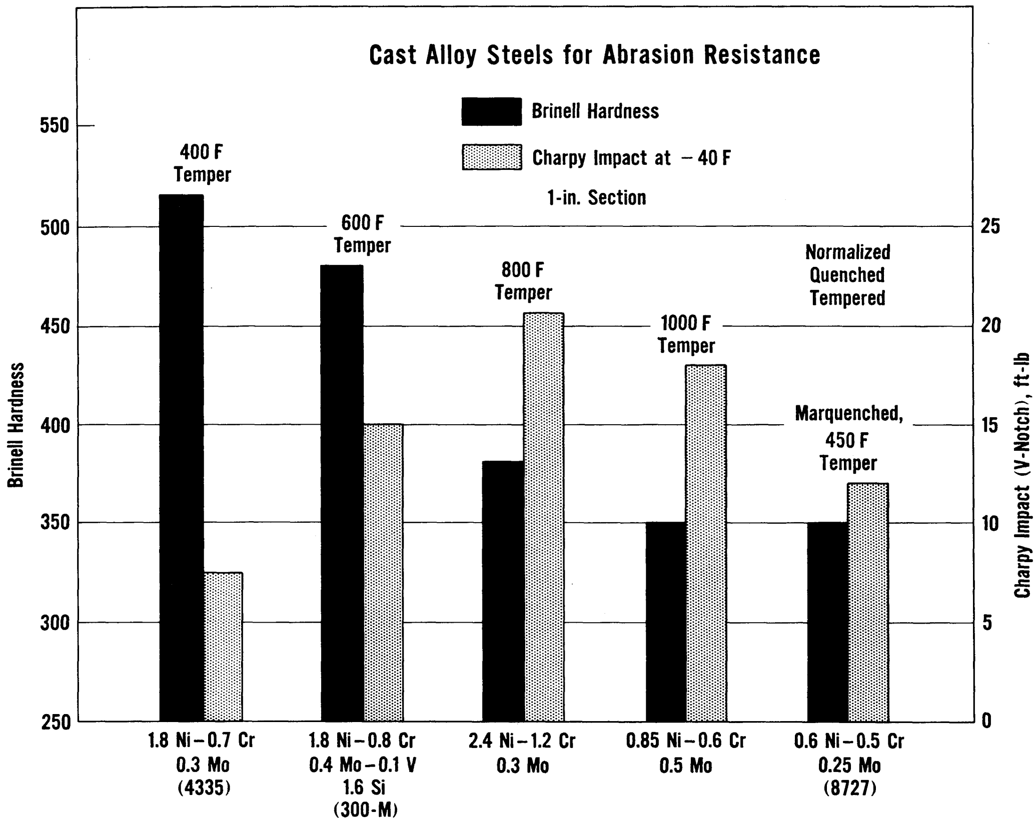
applications. Such applications usually require a compromise between abrasion resistance, which is a function of hardness and carbon content, and toughness to resist the shock usually inherent in the service. Another compromise involves sufficiently high carbon and alloy contents to maintain the required level of hardness throughout the thickness of a casting and at the same time meet the requirement that castings should be readily weldable for fabrication or field maintenance.

The 4335 steel, Figure 22, would be expected to have maximum abrasion resistance because of its high hardness. Along with the 300-M and 2.4 nickel-1.2 chromium-0.3 molybdenum steels, it has sufficient hardenability for heavy sections. Toughness varies inversely with hardness for all steels and, in general, weldability is inverse to carbon content. Therefore, the 2.4 nickel-1.2 chromium-0.3 molybdenum and 0.85 nickel-0.6 chromium-0.5 molybdenum types are the most weldable and toughest, although of lower hardness. The 8727 type is usually limited to relatively light section castings, for example, 1½-inch thick maximum, because of its limited hardenability. Typical hardness ranges for a number of applications are shown in Table VII.

TABLE VII

Typical Hardness for Some Applications of the Wear and Abrasion Resistant Cast Steels of Figure 22

Application	Brinell Hardness
Tractor and shovel castings	500
Liners and crusher plates	500
Dipper bucket teeth	300-480
Sand slurry pumps	475
Dredge pumps, crusher jaws, rollers, pinions	470
Gears and hammers	265-380
Rail segments for power shovels	360
Crawler shoes for power shovels	300-350



Steel Type	Composition, %						
	C	Mn	Si	Ni	Cr	Mo	Other
4335	0.33-0.38	0.60-1.00	0.80 max	1.40-2.00	0.55-0.90	0.20-0.40	—
300-M	0.28-0.33	0.60-1.00	1.45-1.80	1.65-2.00	0.65-0.90	0.30-0.45	.05 min V
2.4 Ni-1.2 Cr-0.3 Mo	0.25 max	0.35	0.30	2.40	1.20	0.30	—
0.85 Ni-0.6 Cr-0.5 Mo	0.20 max	0.60-1.00	0.80 max	0.70-1.00	0.40-0.80	0.40-0.60	.03-0.10 V .002-.006 B 0.15-0.50 Cu
8727	0.25-0.30	0.75-1.00	0.80 max	0.40-0.70	0.40-0.60	0.20-0.30	—

Fig. 22. Hardness and toughness of five cast alloy steels for applications requiring resistance to abrasion.[1, 11, 14, 19, 20]

Normalized and Tempered Nickel-Chromium-Molybdenum Types

The higher alloyed grades in Figure 22 are used often with higher carbon contents for abrasion resistant castings that can only be normalized and tempered. For example, steels of the 4300 and 2.4 nickel-1.2 chromium-0.3 molybdenum types are made with 0.40-0.50 per cent carbon to develop 225-250 Brinell hardness for dredge pump casings, impellers and liners. At carbon levels of 0.50-0.60, normalizing and tempering develops hardnesses of 300-600 Brinell for use as mill liners, roll shells and grizzlies. Castings that require even higher hardnesses can utilize carbon contents in the range of 0.60-0.80 per cent.

Austenitic Manganese-Nickel Steel

The nickel-containing grade of austenitic manganese steel, of the Hadfield type, conforms to ASTM A 128, Grade D. It develops the characteristic toughness and work hardening properties by a normalizing treatment in contrast to the water quenching treatment required for the nickel-free grade. The less drastic thermal treatment eliminates the danger of quench cracking. The nickel-modified version retains its strength and toughness after long exposure to temperatures as high as 800 F. This property makes the steel especially useful for applications involving both abrasion and elevated temperatures. Its good abrasion resistance is developed by surface work hardening during use.

Nickel increases the weldability of austenitic manganese steel by preventing precipitation of embrittling grain-boundary carbides during the slow cooling after welding. The nickel grade therefore is advantageous for components that frequently are reconditioned by weld overlaying methods. Table VIII lists the composition, heat treatment and bending properties of this steel.

TABLE VIII

Composition and Bending Properties of Cast Austenitic Manganese-Nickel Steel

STEEL	
Type	13 Mn-3.5 Ni
Specification	ASTM A 128 Class D
COMPOSITION	
Carbon, %	0.7-1.3
Manganese, %	11.5-14.0
Phosphorus, %	.07 max
Silicon, %	1.00 max
Nickel, %	3.0-4.0
HEAT TREATMENT	Hold at 1832 F min to dissolve carbides, air cool.
BENDING PROPERTIES	
When required	If specified in purchase order.
Requirement	Bend at 75 F through 150 deg around a 1-inch dia pin without breaking.

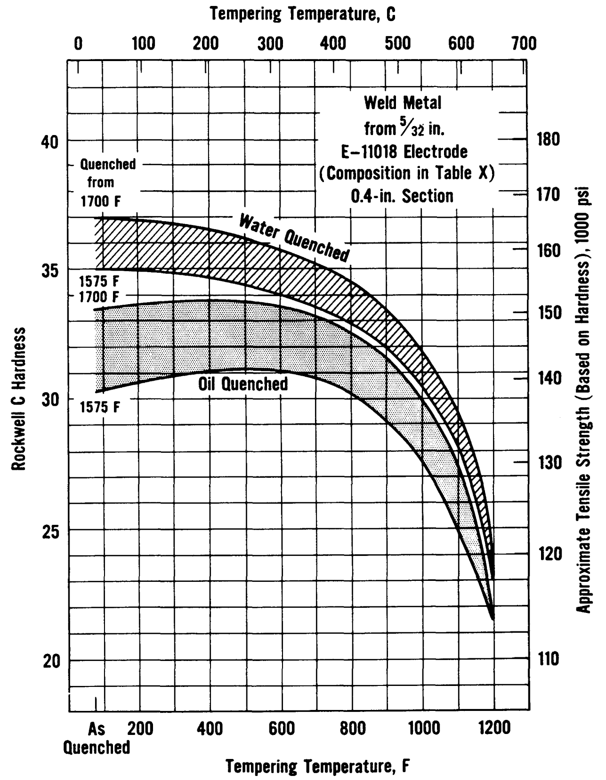


Fig. 23. Effect of quenching and tempering temperatures on hardness and tensile strength of weld metal deposited from E-11018 coated electrode.[27]

WELDING ALLOY STEEL CASTINGS

Basically the same procedures can be used to weld cast alloy steels as for their wrought counterparts. The same weld groove preparations may be used and, as in any weld repair, all defective or contaminated material must be removed. The need for preheat is established by the level of carbon and alloy contents, and the restraint of the weldment. Suggested preheat requirements based on carbon content are listed in Table IX. When welding low-alloy steels with covered electrodes, coatings of the low-hydrogen type are preferred.

The chemical compositions and mechanical properties of weld metal deposited by some coated electrodes are listed in Table X. Table XI gives the mechanical properties required of weld deposits of the 4340 type by Specification MIL-E-8697.

In Table XII the effect of tempering temperature on the properties of HT-4340 weld metal is shown. Information on the tensile strength and hardness of quenched and tempered E-11018 weld metal is shown in Figure 23.

Automatic and semi-automatic MIG and submerged arc processes also can be used to weld cast nickel alloy steels. Because there are differences in the chemical compositions of the wires available from different suppliers, it is best to base selection for a particular application upon information obtained from suppliers. It is particularly important when using the submerged arc process to use the correct flux-wire combination. Some suppliers obtain the properties in the weld metal by adding all of the alloy required through the flux, whereas others introduce some or all of the alloy in the core wire.

References 1 and 21-26 give background information on welding high strength steels and castings.

TABLE IX

Suggested Preheat for Welding Nickel Alloy Steel Castings of Several Carbon Levels

Carbon, %	Temperature, F
0.10-0.20	80-400
0.20-0.30	300-500
0.30-0.45	400-600

TABLE XII

Effect of Tempering Temperature on Properties of HT-4340 Weld Metal

Tempering Temperature*, F	Tensile Strength, psi	Average Charpy Impact (V-Notch), ft-lb, at		
		–40 F	0 F	70 F
450	265,000	13	14	16
800	210,000	10	12	19

* Weld deposits oil quenched from 1550 F.

TABLE X

Composition and Mechanical Properties of Deposited Weld Metal from Electrodes Suitable for Welding Nickel Alloy Steel Castings

ELECTRODE TYPE	MIL-10018	MIL-11018	MIL-12018
COMPOSITION [a]			
Carbon, max, %	0.10	0.10	0.10
Manganese, %	0.75-1.70	1.30-1.80	1.30-2.25
Silicon, max, %	0.60	0.60	0.60
Phosphorus, max, %	.030	.030	.030
Sulfur, max, %	.030	.030	.030
Nickel, %	1.40-2.10	1.25-2.50	1.75-2.25
Chromium, %	0.35 max	0.40 max	0.30-1.50
Molybdenum, %	0.25-0.50	0.30-0.55	0.30-0.55
Vanadium, max, %	.05	.05	.05
MECHANICAL PROPERTIES [a]			
Tensile Strength, min, psi	100,000 [b]	110,000 [b]	120,000 [b]
Yield Strength (0.2% offset), min, psi			
As Welded	90,000-102,000	95,000-107,000	110,000-122,000
Stress Relieved	82,000	87,000	102,000
Elongation (2 in.), min, %	20 [c]	20 [c]	20 [c]
Charpy Impact (V-Notch), average min, ft-lb	20 (–60 F)	20 (–60 F)	20 (–60 F)

[a] Based on Military Specification MIL-E-22200 (1C), the appropriate job specification should be consulted for details of specimen configuration and heat treatment required.

[b] As welded.

[c] As welded or stress relieved.

TABLE XI

Mechanical Properties of Heat-Treated Weld Metal *

ELECTRODE TYPE	Heat Treatment of Weld Metal, F		Tensile Strength, psi	Yield Strength (0.2% Offset), min, psi	Elongation (4 x dia), min, %	Charpy Impact (V-Notch) at 0 F, ft-lb
	Oil Quench	Temper				
HT-4340	1550	1050	150,000-170,000	120,000	8	25
	1550	900	180,000-200,000	145,000	6	12
	1550	800	200,000-220,000	160,000	5	8
HT-4340 (UHS)	1550	450	260,000-280,000	200,000	4	6

* Based on Military Specification MIL-E-8697D. The appropriate job specification should be consulted for details of specimen configuration and heat treatments required.

TABLE XIII

Composition, Heat Treatment, Typical Mechanical Properties and Specifications Met by Castings of Constructional Nickel Alloy Steels

TYPE OF STEEL	1.6 Ni-0.1 V	1.8 Ni-0.3 Mo (4600)	Ni-Mn	1.5 Ni-0.7 Cr (3100)	0.6 Ni-0.6 Cr-0.22 Mo (8600)	1.5 Mn-0.6-Ni-0.6 Cr-0.35 Mo (9500)	3 Ni-1.5 Cr-0.5 Mo (HY-80)
COMPOSITION[a]							
Carbon, %	0.28-0.33	0.28-0.33	0.26-0.32	0.30-0.40	0.25-0.35	0.38 max	0.20 max
Manganese, %	0.80-1.10	0.60-1.00	1.25-1.60	0.60-1.00	1.00 max	1.30-1.70	0.55-0.75
Silicon, %	0.35-0.65	0.35-0.65	0.35-0.65	0.35-0.65	0.80 max	0.80 max	0.50 max
Nickel, %	1.25-1.75	1.50-2.00	1.25-1.75	1.25-1.75	0.40-0.80	0.40-0.80	2.50-3.25
Chromium, %	—	—	—	0.45-0.90	0.40-0.80	0.40-0.80	1.35-1.65
Molybdenum, %	—	0.20-0.40	—	—	0.15-0.30	0.30-0.40	0.30-0.60
Vanadium, %	.08-0.12	—	—	—	—	—	—
HEAT TREATMENT,[b] **F**	N 1600 T 1200	N 1600 T 1200	N 1550 T 1200	WQ 1550 T 1200	N 1750 WQ 1650 T 1250	WQ 1600 T 1100	N 1800 WQ 1550 T 1100 min
TYPICAL PROPERTIES[c]							
Tensile Strength, psi	96,000	91,000	101,000	114,000	115,000	135,000	112,000
Yield Strength, psi	67,000	60,000	68,000	94,000	96,000	115,000	90,000
Elongation (2 in.), %	27	24	25	20	20	20	23
Reduction of Area, %	51	50	55	45	52	45	58
Brinell Hardness	190	190	178	236	230	250	200
Endurance/Tensile Ratio[d]	0.50	0.47	0.50	0.45	0.47	—	—
Charpy Impact (V-Notch), ft-lb	35[e]	18[e]	28[e]	27[f] (—40 F)	40	27[e]	80 (—100 F)
SECTION SIZE CAPABILITY,[g] **in.**	2	4	5	3	2	4	8
SPECIFICATIONS MET	ASTM A 148 (90-60) ASTM A 486 (90) SAE J435a (090) AAR M-201 (C) QQ-S-681 (90-60) MIL-S-15083 (90-60)	ASTM A 148 (80-50) SAE J435a (080) AAR M-201 (B) QQ-S-681 (80-50) MIL-S-15083 (80-50)		ASTM A 148 (105-85) SAE J435a (0105) AAR M-201 (D) QQ-S-681 (105-85) MIL-S-15083 (105-85)	ASTM A 148 (105-85) ASTM A 486 (90) ASTM A 487 (4Q) ASME SA 487 (4Q) SAE J435a (0105) AAR M-201 (D) QQ-S-681 (105-85) MIL-S-15083 (105-85)	ASTM A 148 (120-95) ASTM A 486 (120) ASTM A 487 (6Q) ASME SA 487 (6Q) SAE J435a (0120) AAR M-201 (E) QQ-S-681 (120-95) MIL-S-15083 (120-95)	ASTM A 148 (105-85) SAE J435a (0105) AAR M-201 (D) QQ-S-681 (105-85) MIL-S-10026 MIL-S-10029 MIL-S-11356 MIL-S-12253 MIL-S-15083 (105-85) MIL-S-23008 (HY-80)

TABLE XIII (continued)

TYPE OF STEEL	3.2 Ni-1.6 Cr-0.5 Mo (HY-100)	1.8 Ni-0.7 Cr-0.3 Mo (4300)				
COMPOSITION[a]						
Carbon, %	0.22 max	0.33-0.37				
Manganese, %	0.55-0.75	0.60-1.00				
Silicon, %	0.50 max	0.80 max				
Nickel, %	2.75-3.50	1.40-2.00				
Chromium, %	1.35-1.85	0.55-0.90				
Molybdenum, %	0.30-0.60	0.20-0.40				
Vanadium, %	—	—				
HEAT TREATMENT,[b] **F**	N 1800 WQ 1550 T 1100 min	N 1750 N 1600 T 1200	N 1650 QQ* 1525 T 1125	N 1650 QQ* 1525 T 1000	N 1650 QQ* 1525 T 950	N 1850 QQ* 1600 T 400
TYPICAL PROPERTIES[c]						
Tensile Strength, psi	118,000	114,000	130,000	175,000	185,000	258,000
Yield Strength, psi	104,000	89,000	108,000	155,000	168,000	202,000
Elongation (2 in.), %	20	21	16	14	9.5	10
Reduction of Area, %	55	50	40	32	20	23
Brinell Hardness	215	241	280	377	390	500
Endurance/Tensile Ratio[d]	—	0.49	0.46	0.46	—	—
Charpy Impact (V-Notch), ft-lb	70 (—100 F)	25[e]	21[e]	22	18	19[f] (—40 F)
SECTION SIZE CAPABILITY,[g] **in.**	8	4	4.5	4.5	4.5	3
SPECIFICATIONS MET	ASTM A 148 (120-95) ASTM A 486 (120) SAE J435a (0120) AAR M-201 (E) QQ-S-681 (120-95) MIL-S-10026 MIL-S-10029 MIL-S-11356 MIL-S-12253 MIL-S-15083 (120-95) MIL-S-23008 (HY-100)	ASTM A 148 (90-60) ASTM A 487 (10N) ASME SA 487 (10N) SAE J435a (090) AAR M-201 (C) QQ-S-681 (90-60) MIL-S-15083 (90-60)	ASTM A 148 (120-95) ASTM A 487 (10Q) ASME SA 487 (10Q) SAE J435a (0120) AAR M-201 (E) QQ-S-681 (120-95) MIL-S-15083 (120-95)	ASTM A 148 (175-145) SAE J435a (0175) QQ-S-681 (175-145) MIL-S-10029 MIL-S-12253 MIL-S-15083 (150-125)	MIL-S-10029 MIL-S-46052 (180-150)	MIL-S-46052 (220-180)

[a] Phosphorus, .05% max, sulfur .06% max (Values are lower in a few specifications).

[b] A = Anneal. N = Normalize. WQ = Water Quench. OQ = Oil Quench. T = Temper.

[c] Data on 1 by 1¼ by 6-inch cast test bars.

* Water quenching is used sometimes for simple shapes.

[d] Data on smooth (no notch) test specimens with a standard polish.

[e] Charpy keyhole notch.

[f] Izod impact.

[g] The steels in this table are capable of meeting the specifications listed in the section sizes indicated. However, greater thicknesses may be possible in some cases.

SUMMARY

The compositions and properties of some of the cast nickel alloy steels frequently used for commercial applications are summarized in Tables XIII and XIV. (See pages 20 and 21.)

TABLE XIV

Composition, Heat Treatment, Typical Mechanical Properties and Specifications Met by Castings of Low-Temperature, High-Temperature and Abrasion-Resistant Nickel Alloy Steels

TYPE OF STEEL	Low Temperature		High Temperature		Abrasion Resistant				
	2-3 Ni (LC2)	3-4 Ni (LC3)	0.9 Ni-0.65 Cr-0.5 Mo (WC4)	0.8 Ni-0.7 Cr-1.0 Mo (WC5)	1.8 Ni-0.8 Cr-0.4 Mo-0.1 V-1.6 Si (300-M)	2.4 Ni-1.2 Cr-0.3 Mo	2 Ni-0.8 Cr-0.35 Mo		
COMPOSITION[a]									
Carbon, %	0.25 max	0.15 max	0.20 max	0.20 max	0.28-0.33	0.25	0.48-0.53		
Manganese, %	0.50-0.80	0.50-0.80	0.50-0.80	0.40-0.70	0.60-1.00	0.35	0.70-0.90		
Silicon, %	0.60 max	0.60 max	0.60 max	0.60 max	1.45-1.80	0.30	0.30-0.40		
Nickel, %	2.00-3.00	3.00-4.00	0.70-1.10	0.60-1.10	1.65-2.00	2.40	1.75-2.25		
Chromium, %	—	—	0.50-0.80	0.50-0.90	0.65-0.90	1.20	0.70-0.90		
Molybdenum, %	—	—	0.45-0.65	0.90-1.20	0.30-0.45	0.30	0.30-0.40		
Vanadium, %	—	—	—	—	.05 min	—	—		
HEAT TREATMENT,[b] **F**	N 1700 N 1550 T 1150	N 1700 N 1600 T 1150	N 1900 N 1600 T 1250	N 1900 N 1600 T 1250	OQ 1650 T 600 T 600	WQ 1650 T 800	N 1650	N 1650 T 500	N 1650 T 1250
TYPICAL PROPERTIES[c]									
Tensile Strength, psi	82,000	80,000	87,000[d]	91,000[d]	245,000	188,000	—	—	—
Yield Strength, psi	62,000	54,000	63,000	64,000	200,000	175,000	—	—	—
Elongation (2 in.), %	32	32	27	23	8	10	—	—	—
Reduction of Area, %	54	60	57	58	22	40	—	—	—
Brinell Hardness	160	160	180	192	485	375	490	485	333
Endurance/Tensile Ratio[e]	0.55	0.54	—	—	—	—	—	—	—
Charpy Impact (V-Notch), ft-lb	25 (–100 F)	30 (–150 F)	30	58	15 (–40 F)	21 (–40 F)	—	—	—
SECTION SIZE CAPABILITY,[f] **in.**	2	3	3-4	4-6	—	—	—	—	—
SPECIFICATIONS MET	ASTM A 352 (LC2) ASME SA 352 (LC2)	ASTM A 352 (LC3) ASME SA 352 (LC3)	ASTM A 217 (WC4) ASME SA 217 (WC4)	ASTM A 217 (WC5) ASME SA 217 (WC5)	— —	— —	— —	— —	— —

[a] Phosphorus .05 max, sulfur .06 max (Values are lower in some specifications).

[b] A = Anneal. N = Normalize. WQ = Water Quench. OQ = Oil Quench. T = Temper.

[c] Properties on 1 by 1¼ by 6-inch test bars.

[d]

Type of Steel	Creep Stress, psi, for Creep Rate of .00001%/hour		
	900 F	1000 F	1100 F
WC4	22,500	6300	—
WC5	—	7000	4800

[e] Data on smooth (no notch) test specimens with a standard polish.

[f] The steels in this table are capable of meeting the specificatoins listed in the section sizes indicated. However, greater thicknesses may be possible in some cases.

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