

# **STEEL CASTINGS HANDBOOK**

## **SUPPLEMENT 2**

1999

**SUMMARY OF STANDARD  
SPECIFICATION FOR  
STEEL CASTINGS**



**STEEL FOUNDERS' SOCIETY  
OF AMERICA**

# Steel Castings Handbook Supplement 2

## Summary of Standard Specifications For Steel Castings - 1999

### PREFACE

Supplement 2 will be revised at regular intervals. Supplement 2 is only a summary that is useful in comparing the general requirements in different types of specifications. When ordering, an up-to-date original specification should be used.

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# ORDERING STEEL CASTINGS

## Overview

When making inquiries or ordering parts, all pertinent information must be stated on both the inquiry and order. This information should include all of the following components.

1. Casting shape – either by drawing or pattern. Drawings should include dimensional tolerances, indications of surfaces to be machined, and datum points for locating. If only a pattern is provided, then the dimensions of the casting are as predicted by the pattern.
2. Material specification and grade (e.g. ASTM A 27/A 27M – 95 Grade 60-30 Class 1).
3. Number of parts.
4. Supplementary requirements (e.g. ASTM A 781/A 781M – 95 S2 Radiographic Examination).
  - A. Test methods (e.g. ASTM E 94)
  - B. Acceptance criteria (e.g. ASTM E 186 severity level 2, or MSS SP-54-1995).
5. Any other information that might contribute to the production and use of the part.

To produce a part by any manufacturing process it is necessary to know the design of the part, the material to be used and the testing required. These three elements are discussed in detail in the following sections.

## Design

### **Background**

To obtain the highest quality product, the part should be designed to take advantage of the flexibility of the casting process. The foundry must have either the part drawing or pattern equipment and know the number of parts to be made. To take advantage of the casting process, the foundry should also know which surfaces are to be machined and where datum points are located. Reasonable dimensional tolerances must be indicated where a drawing is provided. Tolerances are normally decided by agreement between the foundry and customer. SFSA Supplement 3 represents a common starting point for such agreements. Supplement 3 is not a specification and care should be taken to reach agreement on what tolerances are required. Close cooperation between the customers' design engineers and the foundry's casting engineers is essential, to optimize the casting design, in terms of cost and performance. Additional guidelines for casting design are given in "Steel Castings Handbook" and Supplement 1, 3, and 4 of the "Steel Castings Handbook".

### **Minimum Section Thickness**

The rigidity of a section often governs the minimum thickness to which a section can be designed. There are cases however when a very thin section will suffice, depending upon strength and rigidity calculations, and when castability becomes the governing factor. In these cases it is necessary that a limit of minimum section thickness per length be adopted in order for the molten steel to completely fill the mold cavity.

Molten steel cools rapidly as it enters a mold. In a thin section close to the gate, which delivers the hot metal, the mold will fill readily. At a distance from the gate, the metal may be too cold to fill the same thin section. A minimum thickness of 0.25" (6 mm) is suggested for design use when conventional steel casting techniques are employed. Wall thicknesses of 0.060" (1.5 mm) and sections tapering down to 0.030" (0.76 mm) are common for investment castings.

### **Draft**

Draft is the amount of taper or the angle, which must be allowed on all vertical faces of a pattern to permit its removal from the sand mold without tearing the mold walls. Draft should be added to the design dimensions but metal thickness must be maintained.

Regardless of the type of pattern equipment used, draft must be considered in all casting designs. Draft can be eliminated by the use of cores; however, this adds significant costs. In cases where the amount of draft may affect the subsequent use of the casting, the drawing should specify whether this draft is to be added to or subtracted from the casting dimensions as given.

The necessary amount of draft depends upon the size of the casting, the method of production, and whether molding is by hand or machine. Machine molding will require a minimum amount of draft. Interior surfaces in green sand molding usually require more draft than exterior surfaces. The amount of draft recommended under normal conditions is about 3/16 inch per foot (approximately 1.5 degrees), and this allowance would normally be added to design dimensions.

## **Parting Line**

Parting parallel to one plane facilitates the production of the pattern as well as the production of the mold. Patterns with straight parting lines, parting lines parallel to a single plane, can be produced more easily and at lower cost than patterns with irregular parting lines.

Casting shapes that are symmetrical about one centerline or plane readily suggest the parting line. Such casting design simplifies molding and coring, and should be used wherever possible. They should always be made as "split patterns" which require a minimum of handwork in the mold, improve casting finish, and reduce costs.

## **Cores**

A core is a separate unit from the mold and is used to create openings and cavities that cannot be made by the pattern alone. Every attempt should be made by the designer to eliminate or reduce the number of cores needed for a particular design to reduce the final cost of the casting. The minimum diameter of a core that can be successfully used in steel castings is dependent upon three factors; the thickness of the metal section surrounding the core, the length of the core, and the special precautions and procedures used by the foundry.

The adverse thermal conditions to which the core is subjected increase in severity as the metal thickness surrounding the core increases and the core diameter decreases. These increasing amounts of heat from the heavy section must be dissipated through the core. As the severity of the thermal condition increases, the cleaning of the castings and core removal becomes much more difficult and expensive.

The thickness of the metal section surrounding the core and the length of the core affect the bending stresses induced in the core by buoyancy forces and therefore the ability of the foundry to obtain the tolerances required. If the size of the core is large enough, rods can often be used to strengthen the core. Naturally, as the metal thickness and the core length increase, the amount of reinforcement required to resist the bending stresses also increases. Therefore, the minimum diameter core must also increase to accommodate the extra reinforcing required.

The cost of removing cores from casting cavities may become prohibitive when the areas to be cleaned are inaccessible. The casting design should provide for openings sufficiently large enough to permit ready access for the removal of the core.

## **Internal Soundness/Directional Solidification**

Steel castings begin to solidify at the mold wall, forming a continuously thickening envelope as heat is dissipated through the mold-metal interface. The volumetric contraction which occurs within a cross section of a solidifying cast member must be compensated by liquid feed metal from an adjoining heavier section, or from a riser which serves as a feed metal reservoir and which is placed adjacent to, or on top of, the heavier section.

The lack of sufficient feed metal to compensate for volumetric contraction at the time of solidification is the cause of shrinkage cavities. They are found in sections which, owing to design, must be fed through thinner sections. The thinner sections solidify too quickly to permit liquid feed metal to pass from the riser to the thicker sections.

## **Machining**

In the final analysis, the foundry's casting engineer is responsible for giving the designer a cast product that is capable of being transformed by machining to meet the specific requirements intended for the function of the part. To accomplish this goal a close relationship must be maintained between the customer's engineering and purchasing staff and the casting producer. Jointly, and with a cooperative approach, the following points must be considered.

1. The molding process, its advantages and its limitations.
2. Machining stock allowance to assure clean up on all machined surfaces.
3. Design in relation to clamping and fixturing devices to be used during machining.

4. Selection of material specification and heat treatment.
5. Quality of parts to be produced.

## **Layout**

It is imperative that every casting design when first produced be checked to determine whether all machining requirements called for on the drawings may be attained. This may be best accomplished by having a complete layout of the sample casting to make sure that adequate stock allowance for machining exists on all surfaces requiring machining. For many designs of simple configuration that can be measured with a simple rule, a complete layout of the casting may not be necessary. In other cases, where the machining dimensions are more complicated, it may be advisable that the casting be checked more completely, calling for target points and the scribing of lines to indicate all machined surfaces.

## **Material**

The material to be used to produce the part must be identified in the order. Material for steel castings is generally ordered to ASTM requirements, although other specifications may be used. This supplement contains a summary of the scope, chemical composition requirements and mechanical property requirements of these material or product specifications. Many requirements are common to several specifications and are given in ASTM A 781/A 781M, ASTM A 703/A 703M, ASTM A 957, ASTM A 985, and ISO 4990.

ASTM A 781/A 781M – 97      CASTINGS, STEEL AND ALLOY, COMMON REQUIREMENTS, FOR GENERAL INDUSTRIAL USE

This specification covers a group of requirements that are mandatory requirements of the following steel casting specifications issued by American Society of Testing and Materials (ASTM). If the product specification specifies different requirements, the product specification shall prevail. ASTM Designations: A 27/A 27M, A 128/A 128M, A 148/A 148M, A 297/A 297M, A 447/A 447M, A 486/A 486M, A 494/A 494M, A 560/A 560M, A 743/A 743M, A 744/A 744M, A 747/A 747M, A 890/A 890M, A 915/A 915M, and A 958.

ASTM A 703/A 703M – 97      STEEL CASTINGS, GENERAL REQUIREMENTS, FOR PRESSURE CONTAINING PARTS

This specification covers a group of common requirements that, unless otherwise specified in an individual specification, shall apply to steel castings for pressure-containing parts under each of the following ASTM specifications. ASTM Designations: A 216/A 216M, A 217/A 217M, A 351/A 351M, A 352/A 352M, A 389/A 389M, A 487/A 487M, A 985, A 990, and A 995.

ASTM A 957 – 96      INVESTMENT CASTINGS, STEEL AND ALLOY, COMMON REQUIREMENTS, FOR GENERAL INDUSTRIAL USE

This specification covers a group of requirements that are mandatory for castings produced by the investment casting process to meet the metallurgical requirements of the following steel casting specifications issued by ASTM. ASTM Designations: A 27/A 27M, A 148/A 148M, A 297/A 297M, A 447/A 447M, A 494/A 494M, A 560/A 560M, A 732/A 732M, A 743/A 743M, A 744/A 744M, A 747/A 747M, A 890/A 890M, and A 915/A 915M.

ASTM A 985 – 98      STEEL INVESTMENT CASTINGS GENERAL REQUIREMENTS, FOR PRESSURE-CONTAINING PARTS

This specification covers a group of common requirements, which are mandatory for steel castings produced by the investment casting process for pressure-containing parts under each of the following ASTM specifications. ASTM Designations: A 216/A 216M, A 217/A 217M, A 351/A 351M, A 352/A 352M, A 389/A 389M, and A 487/A 487M.

## Tests

Testing ensures that the material meets the requirements of the specification; consequently, testing is mandatory. More frequent testing or other tests may be imposed by use of supplementary requirements of product specifications or general requirement specifications. The least testing done consistent with the goals allows for the most economical product.

In addition to specifying test methods, acceptance criteria must be agreed on. The more testing and tighter the acceptance criteria, the more expensive the steel casting produced, without necessarily increasing the quality or serviceability of the steel casting. Hence, the extent of testing and acceptance criteria should be based on the design and service requirements.

*The mechanical properties required are obtained from test bars cast separately from or attached to the castings to which they refer.* The mechanical properties obtained represent the quality of steel, but do not necessarily represent the properties of the castings themselves. Solidification conditions and rate, if cooling during heat treatment, affect the properties of the casting, which in turn are influenced by casting thickness, size, and shape. In particular, the hardenability of some grades may restrict the maximum size at which the required mechanical properties are obtainable.

# SUMMARY OF MATERIAL SPECIFICATIONS FOR CARBON AND ALLOY CAST STEELS

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code makes extensive use of the ASTM specifications with slight modifications. For the sake of comparison, the ASME specifications use the preface SA so that SA 216 is related to ASTM A 216/A 216M. However, while ASTM A 216/A 216M could be used for the sake of comparison of grades, ASME SA 216 contained in Section II, must be used when complying with the code.

The American Iron and Steel Institute (AISI) and the Society of Automotive Engineers (SAE) developed a four number wrought alloy designation system, which is used extensively. These steels have been identified in the AISI classification by a numerical index system that is partially descriptive of the composition. The first digit indicates the type to which the steel belongs. A "1" indicates a carbon steel, a "2" indicates a nickel steel, and a digit greater than "2" indicates alloys other than nickel or alloy combinations. For low alloy steels, the second digit indicates the approximate percentage of the predominant alloy element. Usually the last two or three digits indicate the average carbon content in "points", or hundredths of a percent. Thus, "2340" indicates a nickel steel of approximately 3% nickel (3.25 to 3.75) and 0.40% carbon (0.38 to 0.43). The basic numerals for the various types of AISI steels (including plain-carbon steels) are listed in the table below. The basic numbering system adopted by the Society of Automotive Engineers is quite similar, differing only in minor details. The SAE Handbook should be consulted for comparison.

*AISI Classification System*

<b>Series Designation</b>	<b>Type</b>
10xx	Nonresulphurized carbon steel grades
11xx	Resulphurized carbon steel grades
12xx	Rephosphorized and resulphurized carbon steel grades
13xx	Manganese 1.75%
15xx	Manganese over 1.00 to 1.65%
23xx	Nickel 3.50%
25xx	Nickel 5.00%
31xx	Nickel 1.25% - Chromium 0.65%
33xx	Nickel 3.50% - Chromium 1.55%
40xx	Molybdenum 0.25%
41xx	Chromium 0.50 or 0.95% - Molybdenum 0.12 or 0.20%
43xx	Nickel 1.80% - Chromium 0.50 to 0.80% - Molybdenum 0.25%
44xx	Molybdenum 0.40 or 0.53%
46xx	Nickel 1.55 or 1.80% - Molybdenum 0.20 or 0.25%
47xx	Nickel 1.05% - Chromium 0.45% - Molybdenum 0.20%
48xx	Nickel 3.50% - Molybdenum 0.25%
50xx	Chromium 0.28 or 0.40%
51xx	Chromium 0.80, 0.90, 0.95, 1.00 or 1.05%
5xxx	Carbon 1.00% - Chromium 0.50, 1.00 or 1.45%
61xx	Chromium 0.80 or 0.95% - Vanadium 0.10% or 0.15% min.
81xx	Nickel 0.30 - Chromium 0.40 - Molybdenum 0.12
86xx	Nickel 0.55% - Chromium 0.50 or 0.65% - Molybdenum 0.20%
87xx	Nickel 0.55% - Chromium 0.50% - Molybdenum 0.25%
88xx	Nickel 0.55% - Chromium 0.50% - Molybdenum 0.35%
92xx	Manganese 0.85% - Silicon 2.00%
93xx	Nickel 3.25% - Chromium 1.20% - Molybdenum 0.12%
B	Denotes boron steel (e.g. 51B60)
BV	Denotes boron-vanadium steel (e.g. TS 43BV12 or TS 43BV14)
L	Denotes leaded steel (e.g. 10L18)

Needless to say, this list representing as it does, a standardization and simplification of thousands of alloy-steel compositions, is a very valuable aid to the specification and choice of alloy steels for various applications. Many

of these steels were developed for specific applications, and their continual satisfactory performance has resulted in a considerable degree of standardization of application among these compositions. These designations can be ordered in castings through the use of ASTM A 148/A 148M, A 915/A 915M, or A 958 but care must be used to select a grade with compatible mechanical properties. Also the wrought composition must be modified, especially the silicon and manganese content to allow for casting.

Below is a list of carbon and alloy cast steel specifications, with summary details on the following pages. Note that the values given in the summary of the specifications are stated with either U.S. Conventional Units (USCS) or Metric (SI) units, and are to be regarded separately. Units given in brackets are SI units. The values stated in each system are not exact equivalents (soft conversion); therefore, each system must be used independently of the other. Combining values from the two systems, by using conversion equations (hard conversion), may result in nonconformance with the specification. Also note that the values in the table are given in a minimum over maximum format. This means that if the value is a minimum it will be listed in the upper portion of the specification's table row and in the lower portion of the row if it is a maximum value. Finally, note that tables and their footnotes may be split across two or more pages.

AAR M-201-92	Steel Castings
ABS 2/1.7	Hull Steel Castings
ABS 2/2.23	Steel Castings for Machinery, Boilers, and Pressure Vessels
ASTM A 27/A 27M – 95	Steel Castings, Carbon, for General Application
ASTM A 148/A 148M – 93b	Steel Castings, High Strength, for Structural Purposes
ASTM A 216/A 216M – 93	Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service
ASTM A 217/A 217M – 95	Steel Castings, Martensitic Stainless and Alloy, for Pressure-containing Parts, Suitable for High-Temperature Service
ASTM A 352/A 352M – 93	Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service
ASTM A 356/A 356M – 98	Steel Castings, Carbon, Low Alloy and Stainless Steel, Heavy Walled for Steam Turbines
ASTM A 389/A 389M – 93	Steel Castings, Alloy, Specially Heat-treated, for Pressure-Containing Parts, Suitable for High-Temperature Service
ASTM A 487/A 487M – 93	Steel Castings, Suitable for Pressure Service
ASTM A 597 – 93	Cast Tool Steel
ASTM A 732/A 732M – 98	Castings, Investment, Carbon and Low Alloy, for General Application, and Cobalt Alloy for High Strength at Elevated Temperatures
ASTM A 757/A 757M – 90	Steel Castings, Ferritic and Martensitic for Pressure-Containing and Other Applications, for Low-Temperature Service
ASTM A 915/A 915M – 93	Steel Castings, Carbon, and Alloy, Chemical Requirements Similar to Standard Wrought Grades
ASTM A 958 – 96	Steel Castings, Carbon, and Alloy, with Tensile Requirements, Chemical Requirements Similar to Standard Wrought Grades
FEDERAL QQ-S-681F	Steel Castings
ISO 3755	Cast carbon steels for general engineering
ISO 4991	Steel castings for pressure purposes
ISO 9477	High strength cast steels for general engineering and structural purposes
ISO DIS 13521	Austenitic manganese steel castings
ISO WD 14737(c)	Cast carbon and low alloy steels for general use
Lloyd's Register Rule 2.4.1	Steel Castings part 2, chapter 4, section 1: General requirements
Lloyd's Register Rule 2.4.2	Steel Castings part 2, chapter 4, section 2: Castings for ship and other structural applications
Lloyd's Register Rule 2.4.3	Steel Castings part 2, chapter 4, section 3: Castings for machinery construction
Lloyd's Register Rule 2.4.4	Steel Castings part 2, chapter 4, section 4: Castings for crankshafts
Lloyd's Register Rule 2.4.5	Steel Castings part 2, chapter 4, section 5: Castings for propellers
Lloyd's Register Rule 2.4.6	Steel Castings part 2, chapter 4, section 6: Castings for boilers, pressure vessels and piping systems
Lloyd's Register Rule 2.4.7	Steel Castings part 2, chapter 4, section 7: Ferritic steel castings for low temperature service
Lloyd's Register Rule 2.4.9	Steel Castings part 2, chapter 4, section 9: Steel castings for container corner fittings
MIL-C-24707/1	Castings, Ferrous, for Machinery and Structural Applications
MIL-C-24707/2	Castings, for Pressure Containing Parts Suitable for High Temperature Service
MIL-S-870B	Steel Castings, Molybdenum Alloy
MIL-S-15083B(NAVY)	Steel Castings
MIL-S-15464B(SHIPS)	Steel Alloy, Chromium-Molybdenum; Castings
MIL-S-23008D(SH)	Steel Castings, Alloy, High Yield Strength (HY-80 and HY-100)
MIL-S-46052A(MR)	Steel Castings, High Strength, Low Alloy
SAE J435c	Automotive Steel Castings



These specifications cover carbon and alloy steel castings for locomotive and car equipment and for miscellaneous use graded as A, B, C, D, and E. AAR Specification M-201 provides for all castings unless another AAR Specification for a particular product provides for a variation.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>ABC</sub> Hardness (BHN)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	MPa	%	%										
A	Unannealed	60		30		22	30	108	0.32 <sub>D</sub>	0.90 <sub>D</sub>	0.04	0.04	1.50				
A	A or N	60		30		26	38	160									
B	N or NT	70		38		24	36	106	137	0.32 <sub>D</sub>	0.90 <sub>D</sub>	0.04	0.04	1.50			
C	NT or QT	90		60		22	45	208	179								
D	QT	105		85		17	35	241	0.32	1.85	0.04	0.04	1.50				
E	QT	120		100		14	30	285	0.32	1.85	0.04	0.04	1.50				
								311	0.32	1.85	0.04	0.04	1.50				

<sub>A</sub> Grades D and E steel - composition of the steel, except for coupler locks, shall produce in the standard Jominy test the minimum hardness at 7/16" from the quenched end for the carbon composition as follows, based on the initial composition: up to 0.25% carbon = 30 HRC minimum, 0.25-0.30% carbon = 33 HRC minimum, and 0.31-0.32% carbon = 35 HRC minimum

<sub>B</sub> Impact test - the steel shall possess properties determined by testing standard Charpy V-notch Type "A" specimens prepared as illustrated in Figure 11 in ASTM Designation A 370: grade B 15 ft-lbs @ 20 F, grade C (NT) 15 ft-lbs @ 0 F, grade C (QT) 20 ft-lbs @ -40 F, grade D 20 ft-lbs @ -40 F, and grade E 20 ft-lbs @ -40 F

<sub>C</sub> Dynamic tear and nil ductility test temperature (alternate impact property test): grade B 60 F, grade C (NT) 60 F, grade C (QT) -60 F, grade D -60 F, and grade E -60 F (see original specification for full details)

<sub>D</sub> Grades A and B steel - for each reduction of 0.01% carbon below the maximum specified, an increase of 0.04% manganese above the maximum specified will be permitted to a maximum of 1.2%

Requirements cover carbon-steel castings intended to be used in hull construction and equipment as distinguished from high-temperature applications.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	MPa	%	%										
	A, N, or NT		415		205	24	35										

Requirements cover carbon-steel castings intended to be used in machinery, boiler, and pressure-vessel construction.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	Mpa	%	%										
1	A, N, or NT		415		205	24	35										
2	A, N, or NT		485		250	22	30										
3	A, N, or NT		415		205	24	35										
4	A, N, or NT		485		250	22	35										

ASTM A 27/A 27M – 95

STEEL CASTINGS, CARBON, FOR GENERAL APPLICATION

This specification covers carbon steel castings for general applications that require up to 70 ksi (485 Mpa) minimum tensile strength.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade <sub>A</sub> and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C <sub>B</sub>	Mn <sub>B</sub>	P	S	Si	Ni <sub>C</sub>	Cr <sub>C</sub>	Mo <sub>C</sub>	Other <sub>C</sub>
		ksi	MPa	ksi	MPa	%	%										
N-1									0.25	0.75	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50
N-2	A, N, NT, or QT								0.35	0.60	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50
U-60-30 [415-205]		60	415	30	205	22	30		0.25	0.75	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50
60-30 [415-205] J03000	A, N, NT, or QT	60	415	30	205	24	35		0.30	0.60	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50
65-35 [450-240] J03001	A, N, NT, or QT	65	450	35	240	24	35		0.30	0.70	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50
70-36 [485-250] J03501	A, N, NT, or QT	70	485	36	250	22	30		0.35	0.70	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50
70-40 [485-275] J02501	A, N, NT, or QT	70	485	40	275	22	30		0.25	1.20	0.05	0.06	0.80	0.50	0.50	0.25	Cu 0.50

<sub>A</sub> Specify Class 1 (post weld heat treatment required) or Class 2 (no PWHT needed) in addition to grade designation

<sub>B</sub> For each reduction of 0.01% carbon below the maximum specified, an increase of 0.04% manganese above the maximum specified will be permitted to a maximum of 1.40% for grades 70-40 and 1.00% for other grades

<sub>C</sub> Supplementary requirement not required unless stipulated by customer - maximum content of unspecified elements; total maximum content of unspecified elements is 1.00%

ASTM A 148/A 148M – 93b

STEEL CASTINGS, HIGH STRENGTH, FOR STRUCTURAL PURPOSES

This specification covers carbon steel and alloy steel castings that are to be subjected to higher mechanical stresses than those covered in Specification A 27/A 27M.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>A</sub> Impact	C <sub>B</sub>	Mn <sub>B</sub>	P	S	Si <sub>B</sub>	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
80-40 [550-275]	A, N, NT, or QT	80	550	40	275	18	30				0.05	0.06					
80-50 [550-345]	A, N, NT, or QT	80	550	50	345	22	35				0.05	0.06					
90-60 [620-415]	A, N, NT, or QT	90	620	60	415	20	40				0.05	0.06					
105-85 [725-585] J31575	A, N, NT, or QT	105	725	85	585	17	35				0.05	0.06					
115-95 [795-655]	A, N, NT, or QT	115	795	95	655	14	30				0.05	0.06					
130-115 [895-795]	A, N, NT, or QT	130	895	115	795	11	25				0.05	0.06					
135-125 [930-860]	A, N, NT, or QT	135	930	125	860	9	22				0.05	0.06					
150-135 [1035-930]	A, N, NT, or QT	150	1035	135	930	7	18				0.05	0.06					
160-145 [1105-1000]	A, N, NT, or QT	160	1105	145	1000	6	12				0.05	0.06					
165-150 [1140-1035]	A, N, NT, or QT	165	1140	150	1035	5	20				0.05	0.020					
165-150L [1140-1035L]	A, N, NT, or QT	165	1140	150	1035	5	20	20 ft-lb [27 J]			0.05	0.020					
210-180 [1450-1240]	A, N, NT, or QT	210	1450	180	1240	4	15				0.05	0.020					
210-180L [1450-1240L]	A, N, NT, or QT	210	1450	180	1240	4	15	15 ft-lb [20 J]			0.05	0.020					
260-210 [1795-1450]	A, N, NT, or QT	260	1795	210	1450	3	6				0.05	0.020					
260-210L [1795-1450L]	A, N, NT, or QT	260	1795	210	1450	3	6	6 ft-lb [8 J]			0.05	0.020					

<sub>A</sub> Impact requirements are only applicable to the L grades; test at –40 °F [–40 °C]

<sub>B</sub> Alloying elements shall be selected by the manufacturer unless otherwise specified

This specification covers carbon steel castings for valves, flanges, fittings, or other pressure-containing parts for high-temperature service and of quality suitable for assembly with other castings or wrought-steel parts by fusion welding.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests	C	Mn	P	S	Si	Ni <sub>E</sub>	Cr <sub>E</sub>	Mo <sub>E</sub>	Other
		ksi	MPa	ksi	MPa												
WCA	A, N, NT	60	415	30	205	24	35										
J02502		85	585						0.25 <sub>B</sub>	0.70 <sub>B</sub>	0.04	0.045	0.60	0.50	0.50	0.20	Cu 0.30 <sub>E</sub> V 0.03
WCB	A, N, NT	70	485	36	250	22	35										
J03002		95	655						0.30 <sub>C</sub>	1.00 <sub>C</sub>	0.04	0.045	0.60	0.50	0.50	0.20	Cu 0.30 <sub>E</sub> V 0.03
WCC	A, N, NT	70	485	40	275	22	35										
J02503		95	655						0.25 <sub>D</sub>	1.20 <sub>D</sub>	0.04	0.045	0.60	0.50	0.50	0.20	Cu 0.30 <sub>E</sub> V 0.03

<sup>A</sup> Quench and temper may only be applied if supplemental requirement S15 is specified

<sup>B</sup> For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% manganese above the specified maximum will be permitted up to a maximum of 1.10%

<sup>C</sup> For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% manganese above the specified maximum will be permitted up to a maximum of 1.28%

<sup>D</sup> For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% manganese above the specified maximum will be permitted up to a maximum of 1.40%

<sup>E</sup> Total maximum content of residual elements is 1.00%, unless supplementary requirement S11 is specified

## ASTM A 217/A 217M – 95

## STEEL CASTINGS, MARTENSITIC STAINLESS AND ALLOY, FOR PRESSURE-CONTAINING PARTS, SUITABLE FOR HIGH-TEMPERATURE SERVICE

This specification covers martensitic stainless steel and alloy steel castings for valves, flanges, fittings, and other pressure-containing parts intended primarily for high-temperature and corrosive service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
WC1	NT 1100F [595C]	65	450	35	240	24	35			0.50						0.45	
J12524		90	620						0.25	0.80	0.04	0.045	0.60	0.50 <sub>AB</sub>	0.35 <sub>AB</sub>	0.65	Cu 0.50 <sub>AB</sub> W 0.10 <sub>AB</sub>
WC4	NT 1100F [595C]	70	485	40	275	20	35		0.20	0.50				0.70	0.50	0.45	
J12082		95	655						0.05	0.80	0.04	0.045	0.60	1.10	0.80	0.65	Cu 0.50 <sub>AC</sub> W 0.10 <sub>AC</sub>
WC5	NT 1100F [595C]	70	485	40	275	20	35		0.20	0.40				0.60	0.50	0.90	
J22000		95	655						0.05	0.70	0.04	0.045	0.60	1.00	0.90	1.20	Cu 0.50 <sub>AC</sub> W 0.10 <sub>AC</sub>
WC6	NT 1100F [595C]	70	485	40	275	20	35		0.20	0.50					1.00	0.45	
J12072		95	655						0.05	0.80	0.04	0.045	0.60	0.50 <sub>AB</sub>	1.50	0.65	Cu 0.50 <sub>AB</sub> W 0.10 <sub>AB</sub>
WC9	NT 1250F [675C]	70	485	40	275	20	35		0.18	0.40					2.00	0.90	
J21890		95	655						0.05	0.70	0.04	0.045	0.60	0.50 <sub>AB</sub>	2.75	1.20	Cu 0.50 <sub>AB</sub> W 0.10 <sub>AB</sub>
WC11	NT 1250F [675C]	80	550	50	345	18	45		0.15	0.50				0.30	1.00	0.45	
J11872		105	725						0.21	0.80	0.020	0.015	0.60	0.50 <sub>AB</sub>	1.50	0.65	Cu 0.35 <sub>AB</sub> V 0.03 <sub>AB</sub> Al 0.01 <sub>AB</sub>
C5	NT 1250F [675C]	90	620	60	415	18	35			0.40					4.00	0.45	
J42045		115	795						0.20	0.70	0.04	0.045	0.75	0.50 <sub>AB</sub>	6.50	0.65	Cu 0.50 <sub>AB</sub> W 0.10 <sub>AB</sub>
C12	NT 1250F [675C]	90	620	60	415	18	35			0.35					8.00	0.90	
J82090		115	795						0.20	0.65	0.04	0.045	1.00	0.50 <sub>AB</sub>	10.00	1.20	Cu 0.50 <sub>AB</sub> W 0.10 <sub>AB</sub>
CI2A	NT 1350F [730C]	85	585	60	415	20	45			0.30			0.20		8.0	0.85	Cb 0.060 N 0.030 V 0.18
J84090		110	760						0.12	0.60	0.020	0.018	0.50	0.40	9.5	1.05	Cb 0.100 N 0.070 V 0.25 <sub>A</sub> Al 0.040 <sub>A</sub>
CA15	NT 1100F [595C]	90	620	65	450	18	30								11.5		
J91156		115	795						0.15	1.00	0.040	0.040	1.50	1.00	14.0	0.50	

<sup>A</sup> Maximum specified residual elements

<sup>B</sup> The total maximum content of specified residual elements = 1.00%

<sup>C</sup> The total maximum content of specified residual elements = 0.60%

## ASTM A 352/A 352M – 93

## STEEL CASTINGS, FERRITIC AND MARTENSITIC, FOR PRESSURE-CONTAINING PARTS, SUITABLE FOR LOW-TEMPERATURE SERVICE

This specification covers steel castings for valves, flanges, fittings, and other pressure-containing parts intended primarily for low-temperature service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Impact <sub>A</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
LCA	NT or QT 1100F	60	415	30	205	24	35	13(-25F) [18(-32)]									
J02504	[590C]	85	585						0.25 <sub>B</sub>	0.70 <sub>B</sub>	0.04	0.045	0.60	0.50 <sub>C</sub>	0.50 <sub>C</sub>	0.20	Cu 0.30 <sub>C</sub> V 0.30 <sub>C</sub>
LCB	NT or QT 1100F	65	450	35	240	24	35	13(-50) [18(-46)]									
J03003	[590C]	90	620						0.30 <sub>B</sub>	1.00 <sub>B</sub>	0.04	0.045	0.60	0.50 <sub>C</sub>	0.50 <sub>C</sub>	0.20 <sub>C</sub>	Cu 0.30 <sub>C</sub> V 0.03 <sub>C</sub>
LCC	NT or QT 1100F	70	485	40	275	22	35	15(-50) [20(-46)]									
J02505	[590C]	95	655						0.25 <sub>B</sub>	1.20 <sub>B</sub>	0.04	0.045	0.60	0.50 <sub>C</sub>	0.50 <sub>C</sub>	0.20 <sub>C</sub>	V 0.03 <sub>C</sub>
LC1	NT or QT 1100F	65	450	35	240	24	35	13(-75) [18(-59)]		0.50						0.45	
J12522	[590C]	90	620						0.25	0.80	0.04	0.045	0.60			0.65	
LC2	NT or QT 1100F	70	485	40	275	24	35	15(-100) [20(-73)]		0.50				2.00			
J22500	[590C]	95	655						0.25	0.80	0.04	0.045	0.60	3.00			
LC2-1	NT or QT 1100F	105	725	80	550	18	30	30(-100) [41(-73)]		0.55				2.50	1.35	0.30	
J42215	[590C]	130	895						0.22	0.75	0.04	0.045	0.60	3.50	1.85	0.60	
LC3	NT or QT 1100F	70	485	40	275	24	35	15(-150) [20(-101)]		0.50				3.00			
J31550	[590C]	95	655						0.15	0.80	0.04	0.045	0.60	4.00			
LC4	NT or QT 1050F	70	485	40	275	24	35	15(-175) [20(-115)]		0.50				4.00			
J41500	[570C]	95	655						0.15	0.80	0.04	0.045	0.60	5.00			
LC9	QT 1050-1175F	85	585	75	515	20	30	20(-320) [27(-196)]						8.50			
J31300	[595-635C]								0.13	0.90	0.04	0.045	0.45	10.0	0.50	0.20	Cu 0.30 V 0.03
CA6NM	NT 1050-1150F	110	760	80	550	15	35	20(-100) [27(-73)]						3.5	11.5	0.4	
J91540	[565-620C]	135	930						0.06	1.00	0.04	0.045	1.00	4.5	14.0	1.0	

<sub>A</sub> See original specification for full details – units are in ft-lbs @ (F) and [J @ (C)]

<sub>B</sub> For each reduction of 0.01% carbon below the maximum specified, an increase of 0.04% manganese above the maximum specified will be permitted up to a maximum of 1.10% manganese (Grade LCA), 1.40% manganese (Grade LCC), and 1.28% manganese (Grade LCB)

<sub>C</sub> Specified residual elements – the total content of these elements is 1.00% maximum

## ASTM A 356/A 356M – 98

## STEEL CASTINGS, CARBON, LOW ALLOY AND STAINLESS STEEL, HEAVY WALLED FOR STEAM TURBINES

This specification covers one grade of martensitic stainless steel and several grades of ferritic steel castings for cylinders (shells), valve chests, throttle valves, and other heavy-walled castings for steam turbine applications.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		Ksi	MPa	Ksi	MPa	%	%										
1	NT 1100F [595C]	70	485	36	250	20	35		0.35 <sub>A</sub>	0.70 <sub>A</sub>	0.035	0.030	0.60				
J03502																	
2	NT 1100F [595C]	65	450	35	240	22	35		0.25 <sub>A</sub>	0.70 <sub>A</sub>	0.035	0.030	0.60			0.45	
J12523									0.25 <sub>A</sub>	0.70 <sub>A</sub>	0.035	0.030	0.60			0.65	
5	NT 1100F [595C]	70	485	40	275	22	35		0.25 <sub>A</sub>	0.70 <sub>A</sub>	0.035	0.030	0.60		0.40	0.40	
J12540									0.25 <sub>A</sub>	0.70 <sub>A</sub>	0.035	0.030	0.60		0.70	0.60	
6	NT 1100F [595C]	70	485	45	310	22	35		0.25 <sub>A</sub>	0.50	0.035	0.030	0.60		1.00	0.45	
J12073									0.20	0.80	0.035	0.030	0.60		1.50	0.65	

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		Ksi	MPa	Ksi	MPa	%	%										
8 J12073	NT 1100F [595C]	80	550	50	345	18	45		0.20	0.50	0.035	0.030	0.20		1.00	0.90	V 0.05
9 J21610	NT 1100F [595C]	85	585	60	415	15	45		0.20	0.50	0.035	0.030	0.20		1.50	1.20	V 0.15
10 J22090	NT 1100F [595C]	85	585	55	380	20	35		0.20	0.90	0.035	0.030	0.60		1.00	0.90	V 0.20
12 J80490	NT 1350F [730C]	85	585	60	415	20	-		0.20	0.50	0.035	0.030	0.60		1.50	1.20	V 0.35
CA6NM J91540	NT 1050F [565C]	110	760	80	550	15	35		0.08	0.3	0.02	0.01	0.2	2.00	2.75	0.90	
									0.12	0.6	0.02	0.01	0.5	8.0	9.5	0.85	V 0.18 Cb 0.06 N 0.03
														0.4	1.05	1.05	V 0.25 Cb 0.10 N 0.07 Al 0.04
									0.06	1.00	0.040	0.030	1.00	3.5	11.5	0.4	
														4.5	14.0	1.0	

<sup>A</sup> For each 0.01% reduction in carbon below the maximum specified, an increase of 0.04% points of manganese over the maximum specified for that element may be permitted up to 1.00%

ASTM A 389/A 389M – 93

STEEL CASTINGS, ALLOY, SPECIALLY HEAT-TREATED, FOR PRESSURE-CONTAINING PARTS, SUITABLE FOR HIGH-TEMPERATURE SERVICE

This specification covers alloy steel castings, which have been subjected to special heat treatment, for valves, flanges, fittings, and other pressure-containing parts intended primarily for high-temperature service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sup>A</sup>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	MPa	%	%										
C23 J12080	NT	70	483	40	276	18	35		0.20	0.30	0.04	0.045	0.60		1.00	0.45	V 0.15
C24 J12092	NT	80	552	50	345	15	35		0.20	0.80	0.04	0.045	0.60		1.50	0.65	V 0.25
									0.20	0.30	0.04	0.045	0.60		0.80	0.90	V 0.15
										0.80					1.25	1.20	V 0.25

<sup>A</sup> Refer to original specification for additional information regarding temperature and time requirements for heat treatment

ASTM A 487/A 487M – 93

STEEL CASTINGS, SUITABLE FOR PRESSURE SERVICE

This specification covers low-alloy steels, and martensitic stainless steels in the normalized and tempered, or quenched and tempered condition suitable for pressure-containing parts. The weldability of the classes in the specification varies from readily weldable to weldable only with adequate precautions, and the weldability of each class should be considered prior to assembly by fusion welding.

GRADE & HEAT TREATMENT						MECHANICAL PROPERTIES (min. unless range given)							CHEMICAL COMPOSITION, % (max. percent unless range given)																	
Grade	Class	Austenitizing Temperature min, F [C]	Media A	Quenching Cool Below F [C]	Tempering TemperatureB F [C]	Tensile StrengthH		Yield Strength		Elong	Red Area	Hardness (max) HRC (BHN)	Thickness (max) in [mm]	C	Mn	P	S	Si	Ni	Cr	Mo	Residual Elements							Total	
						Ksi	Mpa	ksi	Mpa													%	Cu	Ni	Cr	Mo	Mo+W	W		V
1 J13002	A	1600 [870]	A	450 [230]	1100 [595]	85	585	55	380	22	40			0.30	1.00	0.04	0.045	0.80					0.50	0.50	0.35		0.25			1.00L
	B	1600 [870]	L	500 [260]	1100 [595]	110	760	65	450	22	45																			
	C	1600 [870]	A or L	500 [260]	1150 [620]	115	795	90	620	65	450	22	45																	
2 J13005	A	1600 [870]	A	450 [230]	1100 [595]	85	585	53	365	22	35			0.30	1.00	0.04	0.045	0.80			0.10	0.30	0.50	0.50	0.35			0.10	0.03	1.00
	B	1600 [870]	L	500 [260]	1100 [595]	110	760	65	450	22	40																			
	C	1600 [870]	A or L	500 [260]	1150 [620]	115	795	90	620	65	450	22	40																	

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4 J13047	A	1600 [870]	A or L	500 [260]	1100 [595]	90	620	60	415	18	40	22 (235)			0.30	1.00	0.04	0.045	0.80	0.40 0.80	0.40 0.80	0.15 0.30	0.50						0.10	0.03	0.60															
	B	1600 [870]	L	500 [260]	1100 [595]	115	795	85	585	17	35																																			
	C	1600 [870]	A or L	500 [260]	1150 [620]	130	895	90	620	60	415																					18	35													
	D	1600 [870]	L	500 [260]	1150 [620]	100	690	75	515	17	35																																			
	E	1600 [870]	L	500 [260]	1100 [595]	115	795	95	655	15	35																																			
6 J13855	A	1550 [845]	A	500 [260]	1100 [595]	115	795	80	550	18	30	2.5 [63.5]		0.05 0.38	1.30 1.70	0.04	0.045	0.80	0.40 0.80	0.40 0.80	0.30 0.40	0.50					0.10	0.03	0.60																	
	B	1550 [845]	L	500 [260]	1100 [595]	120	825	95	655	12	25																																			
7, J12084 8 J22091	A	1650 [900]	L	600 [315]	1100 [595]	115	795	100	690	15	30	22 (235)		0.05 0.20 0.05 0.20	0.60 1.00 0.50 0.90	0.04	0.045	0.80	0.70 1.00	0.40 0.80 2.00 2.75	0.40 0.60 0.90 1.10	0.50					0.10		0.60 <sub>M</sub>																	
	A	1750 [955]	A	500 [260]	1250 [675]	85	585	55	380	20	35																																			
	B	1750 [955]	L	500 [260]	1250 [675]	110	760	105	725	75	585																			17	30															
	C	1750 [955]	L	500 [260]	1250 [675]	100	690		515	17	35																																			
9 J13345	A	1600 [870]	A or L	500 [260]	1100 [595]	90	620	60	415	18	35	22 (235)		0.05 0.33	0.60 1.00	0.04	0.045	0.80		0.75 1.10	0.15 0.30	0.50	0.50				0.10	0.03	1.00																	
	B	1600 [870]	L	500 [260]	1100 [595]	105	725	85	585	16	35																																			
	C	1600 [870]	A or L	500 [260]	1150 [620]	90	620	60	415	18	35																																			
	D	1600 [870]	L	500 [260]	1150 [620]	100	690	75	515	17	35																																			
	E	1600 [870]	L	500 [260]	1100 [595]	115	795	95	655	15	35																																			
10 J23015	A	1550 [845]	A	500 [260]	1100 [595]	100	690	70	485	18	35	22 (235)		0.30	0.60 1.00	0.04	0.045	0.80	1.40 2.00	0.55 0.90	0.20 0.40	0.50					0.10	0.03	0.60																	
	B	1550 [845]	L	500 [260]	1100 [595]	125	860	100	690	15	35																																			
11 J12082	A	1650 [900]	A	600 [315]	1100 [595]	70	484	40	275	20	35	22 (235)		0.05 0.20	0.50 0.80	0.04	0.045	0.60	0.70 1.10	0.50 0.80	0.45 0.65	0.50					0.10	0.03	0.50																	
	B	1650 [900]	L	600 [315]	1100 [595]	105	725	85	585	17	35																																			
12 J22000	A	1750 [955]	A	600 [315]	1100 [595]	70	485	40	275	20	35	22 (235)		0.05 0.20	0.40 0.70	0.04	0.045	0.60	0.60 1.00	0.50 0.90	0.90 1.20	0.50					0.10	0.03	0.50																	
	B	1750 [955]	L	400 [205]	1100 [595]	105	725	85	585	17	35																																			
13 J13080	A	1550 [845]	A	500 [260]	1100 [595]	90	620	60	415	18	35	22 (235)		0.30	0.80 1.10	0.04	0.045	0.60	1.40 1.75		0.20 0.30	0.50		0.40			0.10	0.03	0.75																	
	B	1550 [845]	L	500 [260]	1100 [595]	115	795	105	725	85	585																			17	35															
14 J15580 16 J31200 CA15 J91171	A	1550 [845]	L	500 [260]	1100 [595]	120	825	95	655	14	30	22 (235)		0.55	0.80 1.10	0.04	0.045	0.60	1.40 1.75 1.00 1.40		0.20 0.30	0.50		0.40	0.10		0.10	0.03	0.75																	
	A	1600 [870] <sub>C</sub>	A	600 [315]	1100 [595]	145	1000	70	485	40	275																			22	35															
	A	1750 [955]	A or L	400 [205]	900 [480]	140	965	110	760	10	25																			22 (235)		0.12 <sub>K</sub>	2.10 <sub>K</sub>	0.02	0.02	0.50	1.40		0.20		0.20	0.10		0.10	0.02	0.50
	B	1750 [955]	A or L	400 [205]	1100 [595]	170	1170	130	895	65	450																																			
CA15M J91151 CA6NM J91540	C	1750 [955]	A or L	400 [205]	1150 [620] <sub>DE</sub>	115	795	90	620	60	415	22 (235)																																		
	D	1750 [955]	A or L	400 [205]	1150 [260] <sub>DE</sub>	100	690	75	515	17	35	22 (235)																																		
	A	1750 [955]	A or L	400 [205]	1100 [595]	90	620	65	450	18	30	23 (255) <sub>J</sub>		0.15	1.00	0.040	0.040	0.65	1.0 3.5 4.5	11.5 14.0 14.0	0.15 1.0 0.4 1.0	0.50					0.10	0.05	0.50																	
	A	1850 [1010]	A or L	200 [95]	1050-1150 [565-620] EF	115	795	80	550	15	35																																			
	B	1850 [1010]	A or L	200 [95]	1225-1275 [665-690] EF 1050-1150 [565-620] G	100	690	75	515	17	35			0.06	1.00	0.04	0.03	1.00										0.10	0.05	0.50																

<sub>A</sub> A = air, L = liquid

<sub>B</sub> Minimum temperature unless range is specified

ASTM A 487/A 487M Continued

<sup>c</sup> Double austenitize

<sup>d</sup> Double temper with the final temper at a lower temperature than the intermediate temper

<sup>e</sup> Air cool to below 200F [95C] after first temper

<sup>f</sup> Intermediate

<sup>g</sup> Final

<sup>h</sup> Minimum ksi, unless range is given

<sup>i</sup> Test methods and definitions A 370, Table 3a does not apply to CA6NM – the conversion given is based on CA6NM test coupons (for example, see ASTM STP 756)

<sup>j</sup> Proprietary steel composition

<sup>k</sup> For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.40% manganese above the specified maximum will be permitted up to a maximum of 2.30%

<sup>l</sup> V 0.04-0.12

<sup>m</sup> V 0.03-0.10, B 0.002-0.006, Cu 0.15-0.50

ASTM A 597 – 93

CAST TOOL STEEL

This specification covers tool steel compositions for usable shapes cast by pouring directly into suitable molds and for master heats for remelting and casting.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	MPa												
CA-2									0.95						4.75	0.90	V 0.20
T90102									1.05	0.75	0.03	0.03	1.50		5.50	1.40	V 0.50 <sup>A</sup>
CD-2									1.40						11.00	0.70	V 0.40 Co 0.70
T90402									1.60	1.00	0.03	0.03	1.50		13.00	1.20	V 1.00 <sup>A</sup> Co 1.00 <sup>A</sup>
CD-5									1.35					0.40	11.00	0.70	V 0.35 Co 2.50
T90405									1.60	0.75	0.03	0.03	1.50	0.60 <sup>A</sup>	13.00	1.20	V 0.55 Co 3.50
CS-5									0.50	0.60			1.75			0.20	
T91905									0.65	1.00	0.03	0.03	2.25		0.35	0.80	V 0.35
CM-2									0.78						3.75	4.50	V 1.25 W 5.50
T11302									0.88	0.75	0.03	0.03	1.00	0.25	4.50	5.50	V 2.20 W 6.70 Co 0.25
CS-7									0.45	0.40			0.60		3.00	1.20	
T41907									0.55	0.80	0.03	0.03	1.00		3.50	1.60	
CH-12									0.30						4.75	1.25	V 0.20 W 1.00
T90812									0.40	0.75	0.03	0.03	1.50		5.75	1.75	V 0.50 W 1.70
CH-13									0.30						4.75	1.25	V 0.75
T90813									0.42	0.75	0.03	0.03	1.50		5.75	1.75	V 1.20
CO-1									0.85	1.00					0.40		W 0.40
T91501									1.00	3.00	0.03	0.03	1.50		1.00		W 0.60 V 0.30

<sup>A</sup> Optional element – tool steels have found satisfactory application, either with or without the element present; if desired they should be specified with order

ASTM A 732/A 732M – 98

CASTINGS, INVESTMENT, CARBON AND LOW ALLOY, FOR GENERAL APPLICATION, AND COBALT ALLOY FOR HIGH STRENGTH AT ELEVATED TEMPERATURES

This specification covers carbon and low-alloy steel castings made by the investment casting process.



GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Stress Rupture <sub>B</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	MPa												
1A	A	60	414	40	276	24			0.15	0.20			0.20				
J02002									0.25	0.60	0.04	0.045	1.00	0.50 <sub>C</sub>	0.35 <sub>C</sub>		Cu 0.50 <sub>C</sub> Mo+W 0.25 <sub>C</sub>
2A	A	65	448	45	310	25			0.25	0.70			0.20				
J03011									0.35	1.00	0.04	0.045	1.00	0.50 <sub>C</sub>	0.35 <sub>C</sub>		Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
2Q	QT	85	586	60	414	10			0.25	0.70			0.20				
J03011									0.35	1.00	0.04	0.045	1.00	0.50 <sub>C</sub>	0.35 <sub>C</sub>		Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
3A	A	75	517	48	331	25			0.35	0.70			0.20				
J04002									0.45	1.00	0.04	0.045	1.00	0.50 <sub>C</sub>	0.35 <sub>C</sub>		Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
3Q	QT	100	689	90	621	10			0.35	0.70			0.20				
J04002									0.45	1.00	0.04	0.045	1.00	0.50 <sub>C</sub>	0.35 <sub>C</sub>		Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
4A	A	90	621	50	345	20			0.45	0.70			0.20				
									0.55	1.00	0.04	0.045	1.00				Cu 0.50 <sub>D</sub> W 0.10 <sub>D</sub>
4Q	QT	125	862	100	689	5			0.45	0.70			0.20				
									0.55	1.00	0.04	0.045	1.00				Cu 0.50 <sub>D</sub> W 0.10 <sub>D</sub>
5N	NT	85	586	55	379	22			0.30	0.70			0.20				V 0.05
J13052										1.00	0.04	0.045	0.80	0.50 <sub>C</sub>	0.35 <sub>C</sub>		V 0.15 Cu 0.50 <sub>C</sub> Mo+W 0.25 <sub>C</sub>
6N	NT	90	621	60	414	20				1.35			0.20			0.25	
J13512									0.35	1.75	0.04	0.045	0.80	0.50 <sub>C</sub>	0.35 <sub>C</sub>	0.55	Cu 0.50 <sub>C</sub> W 0.25 <sub>C</sub>
7Q	QT	150	1030	115	793	7			0.25	0.40			0.20		0.80	0.15	
J13045									0.35	0.70	0.04	0.045	0.80		1.10	0.25	Cu 0.50 <sub>D</sub> W 0.10 <sub>D</sub>
8Q	QT	180	1241	145	1000	5			0.35	0.70			0.20		0.80	0.15	
J14049									0.45	1.00	0.04	0.045	0.80	0.50 <sub>C</sub>	1.10	0.25	Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
9Q	QT	150	1030	115	793	7			0.25	0.40			0.20	1.65	0.70	0.20	
J23055									0.35	0.70	0.04	0.045	0.80	2.00	0.90	0.30	Cu 0.50 <sub>D</sub> W 0.10 <sub>D</sub>
10Q	QT	180	1241	145	1000	5			0.35	0.70			0.20	1.65	0.70	0.20	
J24054									0.45	1.00	0.04	0.045	0.80	2.00	0.90	0.30	Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
11Q	QT	120	827	100	689	10			0.15	0.40			0.20	1.65		0.20	
J12094									0.25	0.70	0.04	0.045	0.80	2.00	0.35 <sub>C</sub>	0.30	Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
12Q	QT	190	1310	170	1172	4			0.45	0.65			0.20		0.80		V 0.15
J15048									0.55	0.95	0.04	0.045	0.80	0.50 <sub>C</sub>	1.10		Cu 0.50 <sub>C</sub> Mo+W 0.10 <sub>C</sub> W 0.10 <sub>C</sub>
13Q	QT	105	724	85	586	10			0.15	0.65			0.20	0.40	0.40	0.15	
J12048									0.25	0.95	0.04	0.045	0.80	0.70	0.70	0.25	Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
14Q	QT	150	1030	115	793	7			0.25	0.65			0.20	0.40	0.40	0.15	
J13051									0.35	0.95	0.04	0.045	0.80	0.70	0.70	0.25	Cu 0.50 <sub>C</sub> W 0.10 <sub>C</sub>
15A	A							HRB 100 max.	0.95	0.25			0.20		1.30		
J19966									1.10	0.55	0.04	0.045	0.80	0.50 <sub>D</sub>	1.60		Cu 0.50 <sub>D</sub> W 0.10 <sub>D</sub>
21	as cast	52 <sub>A</sub>	360 <sub>A</sub>			10		23.0 [160]	0.20				1.75	25	5		
									0.30	1.00	0.04	0.04	1.00	3.75	29	6	Fe 3 B 0.007 Co remainder
31	as cast	55 <sub>A</sub>	380 <sub>A</sub>			10		30.0 [205]	0.45					9.5	24.5		W 7 B 0.005 Co remainder
									0.55	1.00	0.04	0.04	1.00	11.5	26.5		W 8 B 0.015 Fe 2

<sub>A</sub> Test at elevated temperature, 1500F [820C]<sub>B</sub> Stress rupture test at 1500F [820C], stress units in ksi [MPa], the minimum rupture life is 15 hours with a minimum elongation in 4D of 5%<sub>C</sub> Total of unspecified elements is 1.00%<sub>D</sub> Total of unspecified elements is 0.60%

ASTM A 757/A 757M – 90

STEEL CASTINGS, FERRITIC AND MARTENISTIC FOR PRESSURE-CONTAINING AND OTHER APPLICATIONS, FOR LOW-TEMPERATURE SERVICE

This specification covers carbon and low-alloy steel castings for pressure-containing and other applications intended primarily for petroleum and gas pipelines in areas subject to low-ambient temperatures. Castings shall be heat treated by normalizing and tempering or liquid quenching and tempering. All classes are weldable under proper conditions. Hardenability of some grades may limit useable section size.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests <sub>A</sub> Impact <sub>B</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		Ksi	MPa	Ksi	MPa												
A1Q J03002	QT 1100F [595C]	65	450	35	240	24	35	13(-50) [17(-46)]	0.30	1.00	0.025	0.03	0.60	0.50 <sub>E</sub>	0.40 <sub>E</sub>	0.25 <sub>E</sub>	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
A2Q J02503	QT 1100F [595C]	70	485	40	275	22	35	15(-50) [20(-46)]	0.25 <sub>D</sub>	1.20 <sub>D</sub>	0.025	0.03	0.60	0.50 <sub>E</sub>	0.40 <sub>E</sub>	0.25 <sub>E</sub>	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
B2N, B2Q J22501	NT or QT 1100F [595C]	70	485	40	275	24	35	15(-100) [20(-73)]	0.25	0.50	0.025	0.03	0.60	2.0	0.40 <sub>E</sub>	0.25 <sub>E</sub>	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
B3N, B3Q J31500	NT or QT 1100F [595C]	70	485	40	275	24	35	15(-150) [20(-101)]	0.25	0.80	0.025	0.03	0.60	3.0	0.40 <sub>E</sub>	0.25 <sub>E</sub>	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
B4N, B4Q J41501	NT or QT 1050F [595C]	70	485	40	275	24	35	15(-175) [20(-115)]	0.15	0.50	0.025	0.03	0.60	4.0	0.40 <sub>E</sub>	0.25 <sub>E</sub>	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
C1Q J12582	QT 1100F [595C]	75	515	55	380	22	35	15(-50) [20(-46)]	0.15	0.80	0.025	0.03	0.60	5.0	0.40 <sub>E</sub>	0.25 <sub>E</sub>	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
D1N1, D1Q1 J22092	NT or QT 1100F [595C]	85	585	55	380	20	35	c	0.25	1.20	0.025	0.03	0.60	1.5	0.40 <sub>E</sub>	0.30	V 0.30 <sub>E</sub> Cu 0.50 <sub>E</sub>
D1N2, D1Q2 J22092	NT or QT 1100F [595C]	115	795	75	515	18	35	c	0.20	0.40	0.025	0.03	0.60	2.0	0.90	1.20	V 0.03 <sub>E</sub> Cu 0.50 <sub>E</sub> W 0.10 <sub>E</sub>
D1N3, D1Q3 J22092	NT or QT 1100F [595C]	95	655	75	515	18	35	c	0.20	0.80	0.025	0.03	0.60	2.0	0.90	1.20	V 0.03 <sub>E</sub> Cu 0.50 <sub>E</sub> W 0.10 <sub>E</sub>
E1Q J42220	QT 1100F [595C]	125	860	85	585	15	30	c	0.20	0.80	0.025	0.03	0.60	0.50 <sub>E</sub>	2.75	1.20	V 0.03 <sub>E</sub> Cu 0.50 <sub>E</sub> W 0.10 <sub>E</sub>
E2N1, E2Q1	NT or QT 1100F [595C]	105	725	85	585	15	30	20(-100) [27(-73)]	0.20	0.70	0.020	0.020	0.60	2.75	1.50	0.40	V 0.30 <sub>F</sub> Cu 0.50 <sub>F</sub> W 0.10 <sub>F</sub>
E2N2, E2Q2	NT or QT 1100F [595C]	135	930	100	690	13	30	15(-100) [20(-73)]	0.20	0.40	0.020	0.020	0.60	3.90	2.0	0.60	V 0.30 <sub>F</sub> Cu 0.50 <sub>F</sub> W 0.10 <sub>F</sub>
E2N3, E2Q3	NT QT 1100F [595C]	115	795	100	690	13	30	20(-100) [27(-73)]	0.20	0.70	0.020	0.020	0.60	3.90	2.0	0.60	V 0.30 <sub>F</sub> Cu 0.50 <sub>F</sub> W 0.10 <sub>F</sub>
E3N J91550	NT 1050-1150F [565-620C]	110	760	80	550	15	35	20(-100) [27(-73)]	0.06	1.00	0.030	0.020	1.00	3.5	11.5	0.40	Cu 0.50 <sub>G</sub> W 0.10 <sub>G</sub>

<sub>A</sub> Refer to the original specification for additional information on toughness requirements and effective section size information

<sub>B</sub> See original specification for full details – units are in ft-lbs @ (F) and [J @ (C)]

<sub>C</sub> Requirements shall be subject to agreements between the manufacturer and the purchaser

<sub>D</sub> For each 0.01% carbon below the maximum specified, an increase of 0.04% manganese over the maximum specified will be permitted up to 1.40%

<sub>E</sub> Total of residuals, including phosphorus and sulfur, is 1.00%

<sub>F</sub> Total of residuals, including phosphorus and sulfur, is 0.70%

<sub>G</sub> Total of residuals, including phosphorus and sulfur, is 0.50%

## ASTM A 915/A 915M – 93

## STEEL CASTINGS, CARBON, AND ALLOY, CHEMICAL REQUIREMENTS SIMILAR TO STANDARD WROUGHT GRADES

This specification covers carbon and low-alloy steel castings having chemical analyses similar to that of the standard wrought grades.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
SC 1020	as cast, A, N, NT, or QT								0.18	0.40			0.30				
J02003										0.23	0.80	0.040	0.040	0.60			
SC 1025	as cast, A, N, NT, or QT								0.22	0.40			0.30				
J02508										0.28	0.80	0.040	0.040	0.60			
SC 1030	A, N, NT, or QT								0.28	0.50			0.30				
J03012										0.34	0.90	0.040	0.040	0.60			
SC 1040	A, N, NT, or QT								0.37	0.50			0.30				
J04003										0.44	0.90	0.040	0.040	0.60			
SC 1045	A, N, NT, or QT								0.43	0.50			0.30				
J04502										0.50	0.90	0.040	0.040	0.60			
SC 4130	A, N, NT, or QT								0.28	0.40			0.30		0.80	0.15	
J13502										0.33	0.80	0.035	0.040	0.60		1.10	0.25
SC 4140	A, N, NT, or QT								0.38	0.70			0.30		0.80	0.15	
J14045										0.43	1.10	0.035	0.040	0.60		1.10	0.25
SC 4330	A, N, NT, or QT								0.28	0.60			0.30	1.65	0.70	0.20	
J23259										0.33	0.90	0.035	0.040	0.60	2.00	0.90	0.30
SC 4340	A, N, NT, or QT								0.38	0.60			0.30	1.65	0.70	0.20	
J24053										0.43	0.90	0.035	0.040	0.60	2.00	0.90	0.30
SC 8620	A, N, NT, or QT								0.18	0.60			0.30	0.40	0.40	0.15	
J12095										0.23	1.00	0.035	0.040	0.60	0.70	0.60	0.25
SC 8625	A, N, NT, or QT								0.23	0.60			0.30	0.40	0.40	0.15	
J12595										0.28	1.00	0.035	0.040	0.60	0.70	0.60	0.25
SC 8630	A, N, NT, or QT								0.28	0.60			0.30	0.40	0.40	0.15	
J13095										0.33	1.00	0.035	0.040	0.60	0.70	0.60	0.25

## ASTM A 958 – 96

## STEEL CASTINGS, CARBON, AND ALLOY, WITH TENSILE REQUIREMENTS, CHEMICAL REQUIREMENTS SIMILAR TO STANDARD WROUGHT GRADES

This specification covers carbon and low-alloy steel castings having chemical analyses similar to that of the standard wrought grades.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)													CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Requirements/Grade Suitability <sub>AC</sub>													C	Mn	P	S	Si	Ni	Cr	Mo	Other
		65/35	70/36	80/40	80/50	90/60	105/85	115/96	130/115	135/125	150/135	160/145	165/150	210/180									
SC 1020	A, N, NT, or QT	X	X												0.18	0.40			0.30				
J02003																0.23	0.80	0.040	0.040	0.60			
SC 1025	A, N, NT, or QT	X	X												0.22	0.40			0.30				
J02508																0.28	0.80	0.040	0.040	0.60			
SC 1030	A, N, NT, or QT	X	X	X	X										0.28	0.50			0.30				
J03012																0.34	0.90	0.040	0.040	0.60			
SC 1040	A, N, NT, or QT	X <sub>B</sub>	X	X	X	X									0.37	0.50			0.30				
J04003																0.44	0.90	0.040	0.040	0.60			
SC 1045	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X							0.43	0.50			0.30				
J04502																0.50	0.90	0.040	0.040	0.60			
SC 4130	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X	X	X	X				0.28	0.40			0.30		0.80	0.15	
J13502																0.33	0.80	0.035	0.040	0.60		1.10	0.25
SC 4140	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X	X	X	X		0.38	0.70			0.30		0.80	0.15	
J14045																0.43	1.10	0.035	0.040	0.60		1.10	0.25

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)													CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Requirements/Grade Suitability <sub>AC</sub>													C	Mn	P	S	Si	Ni	Cr	Mo	Other
		65/35	70/36	80/40	80/50	90/60	105/85	115/96	130/115	135/125	150/135	160/145	165/150	210/180									
SC 4330	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X	X	X	X	X	0.28	0.60			0.30	1.65	0.70	0.20	
J23259															0.33	0.90	0.035	0.040	0.60	2.00	0.90	0.30	
SC 4340	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X	X	X	X	0.38	0.60			0.30	1.65	0.70	0.20	
J24053															0.43	0.90	0.035	0.040	0.60	2.00	0.90	0.30	
SC 8620	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X							0.18	0.60			0.30	0.40	0.40	0.15	
J12095															0.23	1.00	0.035	0.040	0.60	0.70	0.60	0.25	
SC 8625	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X	X	X					0.23	0.60			0.30	0.40	0.40	0.15	
J12595															0.28	1.00	0.035	0.040	0.60	0.70	0.60	0.25	
SC 8630	A, N, NT, or QT	X <sub>B</sub>	X <sub>B</sub>	X	X	X	X	X	X	X	X				0.28	0.60			0.30	0.40	0.40	0.15	
J13095															0.33	1.00	0.035	0.040	0.60	0.70	0.60	0.25	

<sup>A</sup> X denotes that the properties may be achieved by at least one of the heat treatments for this specification

<sup>B</sup> These grades are likely to significantly exceed the minimum strength levels; therefore, problems may be experienced when trying to produce castings to low hardness values

<sup>C</sup> Tensile requirements for the different classes given in the table below

TENSILE REQUIREMENTS													
Class	65/35	70/36	80/40	80/50	90/60	105/85	115/95	130/115	135/125	150/135	160/145	165/150	210/180
Tensile (ksi)	65	70	80	80	90	105	115	130	135	150	160	165	210
Tensile [MPa]	450	485	550	550	620	725	795	895	930	1035	1105	1140	1450
Yield (ksi)	35	36	40	50	60	85	95	115	125	135	145	150	180
Yield [MPa]	240	250	275	345	415	585	655	795	860	930	1000	1035	1240
Elong. (%)	24	22	18	22	18	17	14	11	9	7	6	5	4
Red. A (%)	35	30	30	35	35	35	30	25	22	18	12	10	8

## FEDERAL QQ-S-681F

## STEEL CASTINGS

This specification covers mild-to-medium-strength carbon steel castings for general application as described in ASTM A 27 and high-strength steel castings for structural purposes as described in ASTM A 148.

*Canceled May 20, 1985 – use ASTM A 27 and ASTM A 148*

## ISO 3755

## CAST CARBON STEELS FOR GENERAL ENGINEERING

This International Standard specifies requirements for eight grades of heat-treated cast carbon steels for general engineering purposes. Four of the grades have a restricted chemical composition to ensure uniform weldability.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES <sub>A</sub> (minimum unless range given)							CHEMICAL COMPOSITION <sub>H</sub> , % (maximum percent unless range given)									
Grade and UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength <sub>D</sub>		Elong <sub>E</sub>		Red A %	Other Tests <sub>G</sub>	C <sub>I</sub>	Mn	P	S	Si	Ni <sub>J</sub>	Cr <sub>J</sub>	Mo <sub>J</sub>	Other <sub>J</sub>
		ksi	MPa	ksi	MPa	%	%											
200-400			400		200	25	25		30									
			550															
200-400W <sub>C</sub>			400		200	25	25		45	0.25	1.00	0.035	0.035	0.60	0.40	0.35	0.15	Cu 0.40 V 0.05
			550															
230-450			450		230	22	22		25									
			600															
230-450W <sub>C</sub>			450		230	22	22		45	0.25	1.20	0.035	0.035	0.60	0.40	0.35	0.15	Cu 0.40 V 0.05
			600															
270-480			480		270 <sub>E</sub>	18	18		22									
			630															

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES <sub>A</sub> (minimum unless range given)							CHEMICAL COMPOSITION <sub>H</sub> % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength <sub>D</sub>		Elong <sub>C</sub> %	Red A %	Other Tests <sub>G</sub> Impact (J)	C <sub>I</sub>	Mn	P	S	Si	Ni <sub>J</sub>	Cr <sub>J</sub>	Mo <sub>J</sub>	Other <sub>J</sub>
		ksi	MPa	ksi	MPa												
270-480W <sub>C</sub>			480		270 <sub>E</sub>	18	18	22	0.25	1.20	0.035	0.035	0.60	0.40	0.35	0.15	Cu 0.40 V 0.05
340-550			550		340 <sub>F</sub>	15	15	20			0.035	0.035					
340-550W <sub>C</sub>			550		340 <sub>F</sub>	15	15	20	0.25	1.50	0.035	0.035	0.60	0.40	0.35	0.15	Cu 0.40 V 0.05

<sub>A</sub> See original specification for additional details on mechanical properties

<sub>B</sub> The type of heat-treatment is left to the discretion of the manufacturer, unless specifically agreed upon at the time of ordering

<sub>C</sub> The W-grades restrict the chemical composition and may be ordered to ensure uniform weldability

<sub>D</sub> If measurable, the upper yield stress, otherwise the 0.2% proof stress

<sub>E</sub> The casting will have an upper yield stress of [260 Mpa] and a tensile strength of [500-650 MPa] in sections from [28 mm] up to [40 mm]

<sub>F</sub> The casting will have an upper yield stress of [300 Mpa] and a tensile strength of [570-720 MPa] in sections from [28 mm] up to [40 mm]

<sub>G</sub> By choice, according to the order

<sub>H</sub> The choice of chemical composition in the non-weldable grades shall be left to the discretion of the manufacturer

<sub>I</sub> For each 0.01% reduction of carbon below 0.25%, an increase of 0.04% manganese above the maximum specified will be permitted, to a maximum of 1.20% for grade 200-400W and to 1.40% for grade 270-480W

<sub>J</sub> Maximum content of residual elements, the sum of which shall not exceed 1.00%

## ISO 4991 STEEL CASTINGS FOR PRESSURE PURPOSES

See original specification for details.

## ISO 9477 HIGH STRENGTH CAST STEELS FOR GENERAL ENGINEERING AND STRUCTURAL PURPOSES

This International Standard specifies requirements for four grades of heat-treated cast carbon and alloy steels for general engineering and structural purposes.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES <sub>A</sub> (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Impact (J)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
410-620			620		410	16	40	20			0.035	0.035	0.60				
540-720			720		540	14	35	20			0.035	0.035	0.60				
620-820			820		620	11	30	18			0.035	0.035	0.60				
840-1030			1030		840	7	22	15			0.035	0.035	0.60				

<sub>A</sub> See original specification for additional details on mechanical properties

<sub>B</sub> The type of heat-treatment is left to the discretion of the manufacturer, unless specifically agreed upon at the time of ordering

## ISO DIS 13521 AUSTENITIC MANGANESE STEEL CASTINGS

This International Standard specifies austenitic manganese cast steels for wear resistant service. The grades covered by this International Standard will experience maximum service life in applications where the surface of the castings is subject to impact.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>c</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
GX120MnMo7-1	ST [1040 C] & WQ								1.05	6.0			0.30			0.90	
									1.35	8.0	0.060	0.045	0.90			1.20	
GX110MnMo12-1	ST [1040 C] & WQ								0.75	11.0			0.30			0.90	
									1.35	14.0	0.060	0.045	0.90			1.20	
GX100Mn13 <sub>A</sub>	ST [1040 C] & WQ								0.90	11.0			0.30				
									1.05	14.0	0.060	0.045	0.90				
GX120Mn13 <sub>A</sub>	ST [1040 C] & WQ								1.05	11.0			0.30				
									1.35	14.0	0.060	0.045	0.90				
GX120MnCr13-2	ST [1040 C] & WQ								1.05	11.0			0.30		1.50		
									1.35	14.0	0.060	0.045	0.90		2.50		
GX120MnCr13-3	ST [1040 C] & WQ								1.05	11.0			0.30	3.0			
									1.35	14.0	0.060	0.045	0.90	4.0			
GX120Mn17 <sub>A</sub>	ST [1040 C] & WQ <sub>B</sub>								1.05	16.0			0.30				
									1.35	19.0	0.060	0.045	0.90				
GX90MnMo14	as cast								0.70	13.0			0.30			1.00	
									1.00	15.0	0.070	0.045	0.60			1.80	
GX120MnCr17-2	ST [1040 C] & WQ								1.05	16.0			0.30		1.50		
									1.35	19.0	0.060	0.045	0.90		2.50		

<sub>A</sub> These grades are sometimes used for non-magnetic service

<sub>B</sub> For castings with thicknesses less than [45 mm] and containing less than 0.8% carbon, heat treatment is not required

<sub>C</sub> Bend test, hardness test, and microstructure shall be performed when agreed upon between the purchaser and the manufacturer – see original specification for more details

## ISO WD 14737(c)

## CAST CARBON AND LOW ALLOY STEELS FOR GENERAL USE

See original specification for details.

## Lloyd's Register Rule 2.4.1

## STEEL CASTINGS PART 2, CHAPTER 4, SECTION 1: GENERAL REQUIREMENTS

This Sections gives the general requirements for steel castings intended for use in the construction of ships, other marine structures, machinery, boilers, pressure vessels, and piping systems.

Castings are to be made at foundries approved by LR. See the original specification for additional information such as general test samples, non-destructive examination, defective casting rectification, and identification of castings.

## Lloyd's Register Rule 2.4.2

## STEEL CASTINGS PART 2, CHAPTER 4, SECTION 2: CASTINGS FOR SHIP AND OTHER STRUCTURAL APPLICATIONS

The requirements for carbon-manganese steel castings intended for ship and other structural applications where the design and acceptance tests are related to mechanical properties at ambient temperature are given in this Section.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests <sub>A</sub> Impact	C	Mn	P	S	Si	Ni	Cr	Mo	Other <sub>B</sub>
		ksi	MPa	ksi	MPa												
Normal	A, N, NT [550C], or QT [550]		400		200	25	40		0.23	0.70	0.040	0.040	0.60	<sub>E</sub>	<sub>E</sub>	<sub>E</sub>	Cu <sub>E</sub>
Special	A, N, NT [550C], or QT [550]		400		200	25	40	[27 J @ 0 C]	0.23	1.60	0.035	0.035	0.60	<sub>E</sub>	<sub>E</sub>	<sub>E</sub>	Al 0.015 <sub>CD</sub> Al 0.080 <sub>CD</sub> Cu <sub>E</sub>

### Lloyd's Register Rule 2.4.2 Continued

<sup>A</sup> See original specification for full details on required mechanical tests - castings used in ship construction for the stern-frame, rudder, and propeller shaft supports are to be examined by ultrasonic and magnetic particle methods

<sup>B</sup> For the Special grade, the nitrogen content is to be determined

<sup>C</sup> The total aluminum content may be determined instead of the acid soluble content; in which case the total aluminum content is to be 0.020 – 0.10%

<sup>D</sup> Grain refining elements other than aluminum may be used subject to special agreement with LR

<sup>E</sup> Total of residuals is 0.80% maximum

### Lloyd's Register Rule 2.4.3 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 3: CASTINGS FOR MACHINERY CONSTRUCTION

This Section gives the material requirements for carbon-manganese steel castings intended for use in machinery construction and which are not within the scope of Sections 4 to 7.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>B</sub>	C <sub>C</sub>	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
	A, N, NT [550C], or QT [550]		400		200	25	40		0.40	0.50							
	A, N, NT [550C], or QT [550]		440		220	22	30		0.40	0.50							
	A, N, NT [550C], or QT [550]		480		240	20	27		0.40	1.60	0.040	0.040	0.60	0.40 <sub>D</sub>	0.30 <sub>D</sub>	0.15 <sub>D</sub>	Cu 0.30 <sub>D</sub>
	A, N, NT [550C], or QT [550]		520		260	18	25		0.40	0.50							
	A, N, NT [550C], or QT [550]		560		300	15	20		0.40	1.60	0.040	0.040	0.60	0.40 <sub>D</sub>	0.30 <sub>D</sub>	0.15 <sub>D</sub>	Cu 0.30 <sub>D</sub>
	A, N, NT [550C], or QT [550]		600		320	13	20		0.40	0.50							
	A, N, NT [550C], or QT [550]								0.40	1.60	0.040	0.040	0.60	0.40 <sub>D</sub>	0.30 <sub>D</sub>	0.15 <sub>D</sub>	Cu 0.30 <sub>D</sub>

<sup>A</sup> Stress relief may be required depending on what type of part is cast; see original specifications for additional information

<sup>B</sup> Non-destructive examination varies with the type of part that is cast; see original specifications for additional information

<sup>C</sup> Castings which are intended for parts of a welded fabrication are to be of weldable quality with a carbon content generally not exceeding 0.23%

<sup>D</sup> Total of residuals is 0.80% maximum

### Lloyd's Register Rule 2.4.4 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 4: CASTINGS FOR CRANKSHAFTS

This Section gives the requirements for carbon and carbon-manganese steel castings for semi-built and fully built crankshafts.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests <sub>A</sub> Impact	C <sub>B</sub>	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
	A & FC to [300C], or NT [550C] & FC to [300C]		400		200	28	45	[32 J @ ambient]	0.40	0.50 1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
	A & FC to [300C], or NT [550C] & FC to [300C]		440		220	26	45	[28 J @ ambient]	0.40	0.50 1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
	A & FC to [300C], or NT [550C] & FC to [300C]		480		240	24	40	[25 J @ ambient]	0.40	0.50 1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
	A & FC to [300C], or NT [550C] & FC to [300C]		520		260	22	40	[20 J @ ambient]	0.40	0.50 1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
	A & FC to [300C], or NT [550C] & FC to [300C]		550		275	20	35	[18 J @ ambient]	0.40	0.50 1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>

<sub>A</sub> Each casting is to be examined by ultrasonic testing, and magnetic particle or dye penetrant examination is to be carried out over all surfaces

<sub>B</sub> See original specification for full details on rectification of defective castings - weld repairs are not permitted if the carbon content exceeds 0.30%

<sub>C</sub> Total of residuals is 0.80% maximum

#### Lloyd's Register Rule 2.4.5 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 5: CASTINGS FOR PROPELLERS

This Section gives the requirements for cast steel propellers and propeller blades in carbon-manganese, low alloy and stainless steels. The requirements for copper alloy propellers and blades are given in Chapter 9.1.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>A</sub> Impact <sub>B</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		Ksi	MPa	ksi	MPa	%	%										
Carbon-manganese	A, N, or NT [550C]		400		200	25	40	[20 J]	0.25	0.50							
Low alloy	A, N, or NT [550C]		440		245	20	25	[20 J]		1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
									0.25	0.50							
Martensitic stainless	A, N, or NT [550C]		540		380	19	20	[20 J]		1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
									0.25	0.50							
Martensitic stainless	A, N, or NT [550C]		750		550	19		[30 J]		1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
									0.25	0.50							
Austenitic stainless	A, N, or NT [550C]		450		180	35	35			1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
									0.25	0.50							
Duplex stainless	A, N, or NT [550C]		590		370	20	35	[20 J]		1.60	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub>
									0.25	0.50							

<sub>A</sub> See original specification for full details such as non-destructive testing, rectification of defective castings, identification, and certification

<sub>B</sub> When a general service notation Ice Class 1AS, 1A, 1B, or 1C is required the tests are to be made at [-10 C]; however, for general service or where the notation Ice Class 1D is required the tests are to be made at [0 C].

<sub>C</sub> Total of residuals is 0.80% maximum

#### Lloyd's Register Rule 2.4.6 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 6: CASTINGS FOR BOILERS, PRESSURE VESSELS AND PIPING SYSTEMS

This Section gives the requirements for carbon-manganese and alloy steel castings for boilers, pressure vessels and piping systems for use at temperatures not lower than 0 C.



GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests <sub>A</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		Ksi	MPa	ksi	MPa												
Carbon-manganese	A, N, NT, or QT		485		275	22	25		0.25	0.50							
½Mo	A, N, NT, or QT		655						1.20		0.040	0.040	0.60	0.40 <sub>B</sub>	0.30 <sub>B</sub>	0.15 <sub>B</sub>	Cu 0.30 <sub>B</sub>
			460		260	18	30			0.50						0.45	
			590						0.20	1.00	0.040	0.040	0.60	0.40 <sub>C</sub>	0.30 <sub>C</sub>	0.65	Cu 0.30 <sub>C</sub>
1Cr ½Mo	A, N, NT, or QT		480		280	17	20			0.50					1.00	0.45	
			630						0.20	0.80	0.040	0.040	0.60	0.40 <sub>C</sub>	1.50	0.65	Cu 0.30 <sub>C</sub>
2¼Cr 1Mo	A, N, NT, or QT		540		325	17	20			0.40					2.00	0.90	
			630						0.18	0.70	0.040	0.040	0.60	0.40 <sub>C</sub>	2.75	1.20	Cu 0.30 <sub>C</sub>
½Cr ½Mo ¼V	A, N, NT, or QT		510		295	17	20		0.10	0.40					0.30	0.40	V 0.22
			660						0.15	0.70	0.030	0.030	0.45	0.40 <sub>C</sub>	0.50	0.60	V 0.30 Cu 0.30 <sub>C</sub>

<sub>A</sub> See original specification for full details such as non-destructive examination and mechanical properties for design purposes

<sub>B</sub> Total of residuals is 0.80% maximum

<sub>C</sub> Residual element

## Lloyd's Register Rule 2.4.7 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 7: FERRITIC STEEL CASTINGS FOR LOW TEMPERATURE SERVICE

This Section gives the requirements for castings in carbon-manganese and nickel alloy steels intended for use in liquefied gas piping systems where the design temperature is lower than 0 C, and for other applications where guaranteed impact properties at low temperatures are required.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests <sub>A</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		Ksi	MPa	ksi	MPa												
400 Carbon-manganese	N, NT, or QT		400		200	25	40	[27 J @ -60 C] <sub>B</sub>	0.25	0.70							
			550						1.60		0.030	0.030	0.60	0.80	0.25 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub> V 0.03 <sub>C</sub>
430 Carbon-manganese	N, NT, or QT		430		215	23	35	[27 J @ -60 C] <sub>B</sub>		0.70							
			580						0.25	1.60	0.030	0.030	0.60	0.80	0.25 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub> V 0.03 <sub>C</sub>
460 Carbon-manganese	N, NT, or QT		460		230	22	30	[27 J @ -60 C] <sub>B</sub>		0.70							
			610						0.25	1.60	0.030	0.030	0.60	0.80	0.25 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub> V 0.03 <sub>C</sub>
490 2¼Ni	N, NT, or QT		490		275	20	35	[34 J @ -70 C]		0.50				2.00			
			640						0.25	0.80	0.030	0.025	0.60	3.00	0.25 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub> V 0.03 <sub>C</sub>
490 3½Ni	N, NT, or QT		490		275	20	35	[34 J @ -95 C]		0.50				3.00			
			640						0.15	0.80	0.025	0.020	0.60	4.00	0.25 <sub>C</sub>	0.15 <sub>C</sub>	Cu 0.30 <sub>C</sub> V 0.03 <sub>C</sub>

<sub>A</sub> See original specification for full details

<sub>B</sub> The test temperature for carbon-manganese steels may be [5 C] below the design temperature if the latter is above [-55 C], with a maximum test temperature of [-20 C]

<sub>C</sub> Total of residuals is 0.60% maximum

## Lloyd's Register Rule 2.4.9 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 9: STEEL CASTINGS FOR CONTAINER CORNER FITTINGS

This Section gives the requirements for cast steel corner fittings used in the fabrication of freight and tank containers. The fittings are also to comply with the requirements of the latest edition of International Standard ISO 1161.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>A</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
	N or QT [550C]		430 600		220	25	40		0.20 <sub>D</sub>	0.90 1.50	0.035	0.035	0.50	0.30 <sub>B</sub>	0.25 <sub>B</sub>	0.08 <sub>B</sub>	Cu 0.20 <sub>B</sub> Al 0.015 <sub>C</sub>

<sub>A</sub> See original specification for full details such as ultrasonic or radiographic non-destructive examination, repair of defects, identification, and certification

<sub>B</sub> Total of residuals is 0.70% maximum

<sub>C</sub> The total aluminum content may be determined instead of the acid soluble content; in such cases the total aluminum content is to be not less than 0.02% - aluminum may be replaced partly or totally by other grain refining elements as stated in the approved specification

<sub>D</sub> The carbon equivalent must not exceed 0.45%

## MIL-C-24707/1

## CASTINGS, FERROUS, FOR MACHINERY AND STRUCTURAL APPLICATIONS

This specification covers steel castings for machinery and structural applications below 775 F where impact strength may be a consideration.

PREVIOUS SPECIFICATION MIL-S-15083B (grade)	REPLACEMENT SPECIFICATION MIL-C-24707/1 ASTM specification (grade)	FEDERAL GRADE QQ-S-681F ASTM specification (grade)	EQUIVALENT GRADE MIL-C-24707/1 ASTM specification (grade)
(CW)	A 757 (A1Q) or A 216 (WCA)	A 27 (N-1)	A 757 (A1Q) or A 216 (WCA) or A 217 (WC1)
(B)	A 757 (A1Q) or A 216 (WCA)	A 27 (N-2)	A 757 (A1Q) or A 216 (WCA) or A 217 (WC1)
(65-35)	A 757 (A1Q) or A 216 (WCB)	A 27 (U60-30)	A 757 (A1Q) or A 216 (WCB) or A 217 (WC1)
(70-36)	A 757 (A2Q) or A 216 (WCB, WCC)	A 27 (60-30)	A 757 (A1Q) or A 216 (WCB) or A 217 (WC1)
(80-40)	A 757 (A2Q) or A 487 (2 class A, B, C)	A 27 (65-35)	A 757 (A1Q) or A 216 (WCB) or A 217 (WC1)
(80-50)	A 757 (C1Q) or A 487 (2 class A, B, C)	A 27 (70-36)	A 757 (A2Q) or A 216 (WCB, WCC)
(90-60)	A 757 (E1Q) or A 487 (4 class A)	A 27 (70-40)	A 757 (A2Q) or A 216 (WCC)
(100-70)	A 757 (E2N1/E2Q1)	A 148 (80-40)	A 757 (A2Q) or A 487 (2 class A, B, C)
(105-85)	A 757 (E2N2/E2Q2) or A 487 (4 class B)	A 148 (80-50)	A 757 (C1Q) or A 487 (2 class A, B, C)
(120-95)	A 757 (E2N3/E2Q3) or A 487 (14 class A)	A 148 (90-60)	A 757 (E1Q) or A 487 (4 class A)
(150-125)	Special application only	A 148 (105-85)	A 757 (E2N2/E2Q2) or A 487 (4 class B)
		A 148 (120-95)	A 757 (E2N3/E2Q3) or A 487 (14 class A)

Additional notes for specification are as follows; see original military specification booklet for further information, including Quality Assurance Provisions. The specified residual elements shall be determined for carbon steels. When no impact requirement is given, there shall be a requirement of 20 ft-lbs @ 10 F; except for deck applications, which shall meet a requirement of 20 ft-lbs @ -20 F. When specified, the stress relieving temperature shall be 50 F [30 C] but not more than 100 F [60 C] below the tempering temperature; mechanical properties shall be determined after the stress relief heat treatment.

## MIL-C-24707/2

## CASTINGS, FOR PRESSURE CONTAINING PARTS SUITABLE FOR HIGH TEMPERATURE SERVICE

This specification covers alloy steel castings for machinery, structural, and pressure containing parts for high temperature applications.

PREVIOUS SPECIFICATION MIL specification (grade)	REPLACEMENT SPECIFICATION MIL-C-24707/2 ASTM specification (grade)
MIL-S-870B	A 217 (WC1)
MIL-S-15464B(SHIPS) (1)	A 217 (WC6)
MIL-S-15464B(SHIPS) (2)	A 217 (WC9)
MIL-S-15464B(SHIPS) (3)	A 389 (C23)

Additional notes for specification are as follows; see original military specification booklet for further information, including Quality Assurance Provisions. When specified, the stress relieving temperature shall be 50 F [30 C] but not more than 100 F [60 C] below the tempering temperature; mechanical properties shall be determined after the stress relief heat treatment.

MIL-S-870B STEEL CASTINGS, MOLYBDENUM ALLOY

*Canceled January 27, 1989 – use MIL-C-24707/2, grade WC1*

MIL-S-15083B(NAVY) STEEL CASTINGS

*Canceled January 27, 1989 – use MIL-C-24707/1*

MIL-S-15464B(SHIPS) STEEL ALLOY, CHROMIUM-MOLYBDENUM; CASTINGS

*Canceled January 27, 1989 – use MIL-C-24707/2*

MIL-S-23008D(SH) STEEL CASTINGS, ALLOY, HIGH YIELD STRENGTH (HY-80 AND HY-100)

This specification covers grade HY-80 and grade HY-100 steel castings intended for critical structural applications where a weldable, notch-tough, high-strength material is required.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade And UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Impact	C	Mn	P	S	Si	Ni	Cr	Mo	Other <sub>C</sub>
		ksi	MPa	Ksi	MPa												
HY-80 <sub>A</sub> J42015	QT 1190F [643C]			80 99.5	552 686	20	35	<sub>B</sub>	0.20	0.55 0.75	0.014	0.008	0.50	2.75 3.25	1.35 1.60	0.30 0.60	V 0.03 Ti 0.02 Cu 0.25 As 0.025 Sn 0.030 Sb 0.025
HY-100 <sub>A</sub> J42240	QT 1150F [621C]			100 120	690 793	18	30	<sub>B</sub>	0.22	0.55 0.75	0.014	0.008	0.50	3.00 3.50	1.35 1.65	0.30 0.60	

<sub>A</sub> Chemical, tension test, Charpy V-notch, and drop-weight test shall be performed on the castings (see original military specification booklet for further information)

<sub>B</sub> Impact requirements for material in cross-section greater than or equal to 1/2" [13 mm]: 50 ft-lbs [68 J] @ -100 F [-73 C], or 70 ft-lbs [95 J] @ 0 F [-18 C]

<sub>C</sub> Element shall not be added intentionally

MIL-S-46052A(MR) STEEL CASTINGS, HIGH STRENGTH, LOW ALLOY

This specification covers high strength, low alloy, steel castings.

*Canceled May 31, 1983 – use ASTM A 148 as follows: for MIL class 180-150 use grade 165-150L, for MIL class 220-180 use grade 210-180L, and for MIL class 260-210 use grade 260-210L.*

SAE J435c AUTOMOTIVE STEEL CASTINGS

These specifications cover steel castings used in the automotive and allied industries (last revised July 1974).

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests Hardness (BHN) <sub>C</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	Ksi	MPa	%	%										
0022									0.12	0.50							
J01700								187	0.22	0.90	0.040	0.045	0.60				B <sub>F</sub>
0025		60	413.7	30	206.8	22	30										
J02507								187	0.25 <sub>E</sub>	0.75 <sub>E</sub>	0.040	0.045	0.80				B <sub>F</sub>
0030		65	448.2	35	241.3	24	35	131									
J03010								187	0.30 <sub>E</sub>	0.70 <sub>E</sub>	0.040	0.045	0.80				B <sub>F</sub>
0050A		85	586.0	45	310.3	16	24	170	0.40	0.50							
J04501								229	0.50	0.90	0.040	0.045	0.80				B <sub>F</sub>
0050B <sub>A</sub>		100	689.5	70	482.6	10	15	207	0.40	0.50							
J04501								255	0.50	0.90	0.040	0.045	0.80				B <sub>F</sub>
080		80	551.6	50	344.7	22	35	163									
								207			0.040	0.045					B <sub>F</sub>
090		90	620.5	60	413.7	20	40	187									
								241			0.040	0.045					B <sub>F</sub>
0105 <sub>B</sub>		105	723.9	85	586.0	17	35	217									
								248			0.040	0.045					B <sub>F</sub>
0120 <sub>B</sub>		120	827.4	95	655.0	14	30	248									
								311			0.040	0.045					B <sub>F</sub>
0150 <sub>B</sub>		150	1034.2	125	861.8	9	22	311									
								363			0.040	0.045					B <sub>F</sub>
0175 <sub>B</sub>		175	1206.6	145	999.7	6	21	363									
								415			0.040	0.045					B <sub>F</sub>
HA	NQ 1650F, A 1600F							<i>D</i>	0.25								
									0.34								
HB	NQ 1650F, A 1600F							<i>D</i>	0.25								
									0.34								
HC	NQ 1600F, A 1550F							<i>D</i>	0.25								
									0.34								

<sub>A</sub> Properties require a liquid quench and temper (casting section should be 1" or less)

<sub>B</sub> Hardenability requirements when specified

<sub>C</sub> Obtain from parts in location not over 3" thickness

<sub>D</sub> HRC hardness per distance from quench (see original specification for full details)

<sub>E</sub> For each reduction of 0.01% carbon below the maximum specified, an increase of 0.04% manganese above the maximum specified will be permitted to a maximum of 1% manganese

<sub>F</sub> 0.003 – 0.007% B with 1.35% manganese maximum may be used as an optional alloying element when agreed upon

# SUMMARY OF MATERIAL SPECIFICATIONS FOR HIGH ALLOY CAST STEELS

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code makes extensive use of ASTM specifications with slight modifications. For the sake of comparison the ASME specifications use the preface SA so that SA 351 is related to ASTM A 351/A 351M. However, while ASTM A 351/A 351M could be used for comparison of grades, the ASME SA 351 contained in Section II must be used when complying with the code.

Cast stainless steels are most often specified on the basis of composition using the alloy designation system adopted by the Alloy Casting Institute (ACI). These ACI alloy designations, e.g. CF-8M, have been adopted by ASTM and are preferred for cast alloy over the corresponding wrought steel designation of the American Iron and Steel Institute (AISI). The reason for this is that the grades intentionally have different compositions than their wrought counterparts.

The ranges of iron, chromium, and nickel for the cast alloy compositions most widely used are identified with a letter which is part of the ACI grade designation. The initial letter of the grade designation, C or H, indicates whether the alloy is intended primarily for aqueous corrosion service (C) or elevated temperature, i.e. heat-resistant, service (H). The second letter of the ACI designation denotes the nominal chromium-nickel type. As the nickel content of the grade increases, the letter in the ACI designation increases from A (lowest) to Z (highest). Numerals following the letters relate to the maximum carbon content of the corrosion-resistant (C) alloys. When used with heat resistant grades (H), the numerals are the midpoint of a 0.10 carbon range. If additional alloying elements are included in the grade, they are denoted by the addition of a letter to the ACI designation. Thus, CF-8M is an alloy for corrosion resistant service of the 19% Cr and 9% Ni type with a maximum carbon content of 0.08% and which contains molybdenum.

The CF grade alloys constitute the most technologically important and highest tonnage segment of corrosion-resistant casting production. These 19Cr-9Ni alloys are the cast counterparts of the 18Cr-8Ni or AISI 300 series wrought stainless steels. In general, the cast and wrought alloys possess equivalent resistance to corrosive media and they are frequently used in conjunction with each other.

Important differences do exist, however, between the cast CF grade alloys and their wrought AISI counterparts. Most significant among these is the difference in alloy microstructure in the end-use condition. The CF grade cast alloys are duplex ferrite-in-austenite and usually contain from 5 to 40% ferrite, depending on the particular alloy, whereas their wrought counterparts are fully austenitic. The ferrite in cast stainless with duplex structures is magnetic, a point that is often confusing when cast stainless steels are compared to their wrought counterparts by checking their attraction to a magnet. This difference in microstructures is attributable to the fact that the chemical compositions of the cast and wrought alloys are different by intent. Ferrite is present by intent in cast CF grade stainless steels for three reasons: to provide strength, to improve weldability, and to maximize resistance to corrosion in specific environments.

Below is a list of high alloy cast steel specifications, with summary details on the following pages. Note that the values given in the summary of the specifications are stated with either U.S. Conventional Units (USCS) or Metric (SI) units, and are to be regarded separately. Units given in brackets are SI units. The values stated in each system are not exact equivalents (soft conversion); therefore, each system must be used independently of the other. Combining values from the two systems, by using conversion equations (hard conversion), may result in nonconformance with the specification. Also note that the values in the table are given in a minimum over maximum format. This means that if the value is a minimum it will be listed in the upper portion of the specification's table row and in the lower portion of the row if it is a maximum value. Finally, note that tables and their footnotes may be split across two or more pages.

ASTM A 128/A128M – 93	Steel Castings, Austenitic Manganese
ASTM A 297/A 297M – 97	Steel Castings, Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application
ASTM A 447/A 447M – 93	Steel Castings, Chromium-Nickel-Iron Alloy (25-12 Class), for High-Temperature Service
ASTM A 494/A 494M – 98	Castings, Nickel and Nickel Alloy
ASTM A 560/A 560M – 93	Castings, Chromium-Nickel Alloy
ASTM A 743/A 743M – 98	Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application
ASTM A 744/A 744M – 98	Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service
ASTM A 747/A 747M – 93	Steel Castings, Stainless, Precipitation Hardening
ASTM A 890/A 890M – 97	Castings, Iron-Chromium-Nickel-Molybdenum Corrosion-Resistant, Duplex (Austenitic/Ferritic) for General Application
ASTM A 990 – 98	Castings, Iron-Nickel-Chromium and Nickel Alloys, Specially Controlled for Pressure Retaining Parts for Corrosive Service
ISO 11972	Corrosion-resistant cast steels for general applications
ISO DIS 11973	Heat-resistant cast steels for general purposes
ISO 12725	Nickel and nickel alloy castings
Lloyd's Register Rule 2.4.8	Steel Castings part 2, chapter 4, section 8: Austenitic stainless steel castings
MIL-C-24707/3	Castings, Ferrous, Corrosion-Resistant, Austenitic, Chromium-Nickel
MIL-C-24707/6	Castings, Ferrous, Chromium Steel, for Pressure-Containing Parts Suitable for High-Temperature

This specification covers Hadfield austenitic manganese steel castings and alloy modifications.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade <sub>AB</sub> and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
A	Q 1800F [1000C]								1.05	11.0							
J91109									1.35		0.07		1.00				
B-1	Q 1800F [1000C]								0.9	11.5							
J91119									1.05	14.0	0.07		1.00				
B-2	Q 1800F [1000C]								1.05	11.5							
J91129									1.2	14.0	0.07		1.00				
B-3	Q 1800F [1000C]								1.12	11.5							
J91139									1.28	14.0	0.07		1.00				
B-4	Q 1800F [1000C]								1.2	11.5							
J91149									1.35	14.0	0.07		1.00				
C	Q 1800F [1000C]								1.05	11.5					1.5		
J91309									1.35	14.0	0.07		1.00		2.5		
D	Q 1800F [1000C]								0.7	11.5				3.0			
J91459									1.3	14.0	0.07		1.00	4.0			
E-1	Q 1800F [1000C]								0.7	11.5						0.9	
J91249									1.3	14.0	0.07		1.00			1.2	
E-2	Q 1800F [1000C]								1.05	11.5						1.8	
J91339									1.45	14.0	0.07		1.00			2.1	
F	Q 1800F [1000C]								1.05	6.0						0.9	
J91340									1.35	8.0	0.07		1.00			1.2	

<sup>A</sup> Section size precludes the use of all grades and the producer should be consulted as to grades practically obtainable for a particular design required - final selection shall be by mutual agreement between manufacturer and purchaser

<sup>B</sup> Unless otherwise specified, Grade A will be supplied

This specification covers iron-chromium and iron-chromium-nickel alloy castings for heat-resistant service. The grades covered by this specification are general purpose alloys and no attempt has been made to include heat-resisting alloys used for special production application.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong <sub>B</sub>	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo <sub>C</sub>	Other
		ksi	MPa	ksi	MPa	%	%										
HF		70	485	35	240	25			0.20					8.00	18.0		
J92603									0.40	2.00	0.04	0.04	2.00	12.0	23.0	0.50	
HH		75	515	35	240	10			0.20					11.0	24.0		
J93503									0.50	2.00	0.04	0.04	2.00	14.0	28.0	0.50	
HI		70	485	35	240	10			0.20					14.0	26.0		
J94003									0.50	2.00	0.04	0.04	2.00	18.0	30.0	0.50	
HK		65	450	35	240	10			0.20					18.0	24.0		
J94224									0.60	2.00	0.04	0.04	2.00	22.0	28.0	0.50	
HE		85	585	40	275	9			0.20					8.00	26.0		
J93403									0.50	2.00	0.04	0.04	2.00	11.0	30.0	0.50	

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong <sub>B</sub>	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo <sub>C</sub>	Other
		ksi	MPa	ksi	MPa	%	%										
HT		65	450			4			0.35					33.0	15.0		
N08605									0.75	2.00	0.04	0.04	2.50	37.0	19.0	0.50	
HU		65	450			4			0.35					37.0	17.0		
N08004									0.75	2.00	0.04	0.04	2.50	41.0	21.0	0.50	
HW		60	415						0.35					58.0	10.0		
N08001									0.75	2.00	0.04	0.04	2.50	62.0	14.0	0.50	
HX		60	415						0.35					64.0	15.0		
N06006									0.75	2.00	0.04	0.04	2.50	68.0	19.0	0.50	
HC		55	380												26.0		
J92605									0.50	1.00	0.04	0.04	2.00	4.00	30.0	0.50	
HD		75	515	35	240	8								4.00	26.0		
J93005									0.50	1.50	0.04	0.04	2.00	7.00	30.0	0.50	
HL		65	450	35	240	10			0.20					18.0	28.0		
N08604									0.60	2.00	0.04	0.04	2.00	22.0	32.0	0.50	
HN		63	435			8			0.20					23.0	19.0		
J94213									0.60	2.00	0.04	0.04	2.00	27.0	23.0	0.50	
HP		62.5	430	34	235	4.5			0.35					33	24		
N08705									0.75	2.00	0.04	0.04	2.50	37	28	0.50	

<sub>A</sub> As-cast or as agreed upon by the manufacturer and purchaser

<sub>B</sub> When ICI test bars are used in tensile tests as provided for in this specification, the gage length to reduced section diameter ratio shall be 4:1

<sub>C</sub> Castings having a specified molybdenum range agreed upon by the manufacturer and the purchaser may also be furnished under these specifications

## ASTM A 351/A 351M – 94a CASTINGS, AUSTENITIC, AUSTENITIC-FERRITIC (DUPLEX), FOR PRESSURE-CONTAINING PARTS

This specification covers austenitic and austenitic-ferritic (duplex) steel castings for valves, flanges, fittings, and other pressure-containing parts.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength		Elong <sub>D</sub> %	Red A %	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CF3 J92500	ST	70	485	30	205	35.0			0.03	1.50	0.040	0.040	2.00	8.0 12.0	17.0 21.0	0.50	
CF3A <sub>A</sub> J92800	ST	77	530	35	240	35.0			0.03	1.50	0.040	0.040	2.00	8.0 12.0	17.0 21.0	0.50	
CF8 J92600	ST	70	485	30	205	35.0			0.08	1.50	0.040	0.040	2.00	8.0 11.0	18.0 21.0	0.50	
CF8A <sub>A</sub> J92600	ST	77	530	35	240	35.0			0.08	1.50	0.040	0.040	2.00	8.0 11.0	18.0 21.0	0.50	
CF3M J92800	ST	70	485	30	205	30.0			0.03	1.50	0.040	0.040	1.50	9.0 13.0	17.0 21.0	2.00 3.00	
CF3MA <sub>A</sub> J92800	ST	80	550	37	255	30.0			0.03	1.50	0.040	0.040	1.50	9.0 13.0	17.0 21.0	2.00 3.00	
CF8M J92900	ST	70	485	30	205	30.0			0.08	1.50	0.040	0.040	1.50	9.0 12.0	18.0 21.0	2.00 3.00	
CF3MN	ST	75	515	37	255	35.0			0.03	1.50	0.040	0.040	1.50	9.0 13.0	17.0 21.0	2.00 3.00	N 0.10 N 0.20
CF8C	ST	70	485	30	205	30.0			0.08	1.50	0.040	0.040	2.00	9.0 12.0	18.0 21.0	0.50	Cb <sub>F</sub>



GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength		Elong <sub>A</sub>	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
CF-10	ST	70	485	30	205	35.0			0.04					8.0	18.0		
J92590									0.10	1.50	0.040	0.040	2.00	11.0	21.0	0.50	
CF-10M	ST	70	485	30	205	30.0			0.04					9.0	18.0	2.00	
									0.10	1.50	0.040	0.040	1.50	12.0	21.0	3.00	
CH8	ST	65	450	28	195	30.0								12.0	22.0		
J93400									0.08	1.50	0.040	0.040	1.50	15.0	26.0	0.50	
CH10	ST	70	485	30	205	30.0			0.04					12.0	22.0		
J93401									0.10	1.50	0.040	0.040	2.00	15.0	26.0	0.50	
CH20	ST	70	485	30	205	30.0			0.04					12.0	22.0		
J93402									0.20	1.50	0.040	0.040	2.00	15.0	26.0	0.50	
CK20	ST	65	450	28	195	30.0			0.04					19.0	23.0		
J94202									0.20	1.50	0.040	0.040	1.75	22.0	27.0	0.50	
HK30	as cast	65	450	30	240	10.0			0.25					19.0	23.0		
J94203									0.35	1.50	0.040	0.040	1.75	22.0	27.0	0.50	
HK40	as cast	62	425	30	240	10.0			0.35					19.0	23.0		
J94204									0.45	1.50	0.040	0.040	1.75	22.0	27.0	0.50	
HT30	as cast	65	450	28	195	15.0			0.25					33.0	13.0		
N08603									0.35	2.00	0.040	0.040	2.50	37.0	17.0	0.50	
CF10MC	ST	70	485	30	205	20.0								13.0	15.0	1.75	
J92971									0.10	1.50	0.040	0.040	1.50	16.0	18.0	2.25	Cb <sub>6</sub>
CN7M	ST	62	425	25	170	35.0								27.5	19.0	2.00	Cu 3.0
									0.07	1.50	0.040	0.040	1.50	30.5	22.0	3.00	Cu 4.0
CN3MN	ST 2100F [1150C]	80	550	38	260	35.0								23.5	20.0	6.0	N 0.18
									0.03	2.00	0.040	0.010	1.00	25.5	22.0	7.0	N 0.26 Cu 0.75
CD4MCu <sub>E</sub>	ST 1900F [1040C] <sub>C</sub>	100	690	70	485	16.0								4.75	24.5	1.75	Cu 2.75
									0.04	1.00	0.040	0.040	1.00	6.00	26.5	2.25	Cu 3.25
CE8MN	ST 2050F [1120C] <sub>C</sub>	95	655	65	450	25.0								8.0	22.5	3.0	N 0.10
									0.08	1.00	0.040	0.040	1.50	11.0	25.5	4.5	N 0.30
CG6MMN	ST	85	585	42.5	295	30.0				4.00				11.50	20.50	1.50	Cb 0.10 V 0.10 N 0.20
J93790									0.06	6.00	0.040	0.030	1.00	13.50	23.50	3.00	Cb 0.30 V 0.30 N 0.40
CG8M	ST	75	515	35	240	25.0								9.0	18.0	3.0	
J93000									0.08	1.50	0.04	0.04	1.50	13.0	21.0	4.0	
CF10SMnN	ST	85	585	42.5	295	30.0				7.00				8.0	16.0		N 0.08
									0.10	9.00	0.060	0.030	4.50	9.0	18.0		N 0.18
CT15C	as cast	63	435	25	170	20.0			0.05	0.15				31.0	19.0		Cb 0.50
									0.15	1.50	0.030	0.03	1.50	34.0	21.0		Cb 1.50
CK3MCuN	ST 2100F [1150C] <sub>C</sub>	80	550	38	260	35.0								17.5	19.5	6.0	N 0.18 Cu 0.50
									0.025	1.20	0.045	0.010	1.00	19.5	20.5	7.0	N 0.24 Cu 1.0
CE20N	ST 2225F [1218C] <sub>C</sub>	85	550	40	275	30								8	23		N 0.08
									0.20	1.50	0.040	0.040	1.50	11	26	0.50	N 0.20 Fe balance
CG3M	ST	75	515	35	240	25								9	18	3.0	
									0.03	1.50	0.04	0.04	1.50	13	21	4.0	
CD3MWCuN	ST 2010F [1100C]	100	700	65	450	25								6.5	24	3.0	N 0.20 Cu 0.5 W 0.5
									0.03	1.00	0.030	0.025	1.00	8.5	26 <sub>H</sub>	4.0	N 0.30 Cu 1.0 W 1.0

# ASTM A 351/A 351M Continued

<sup>A</sup> Because of thermal instability of Grades CF3A, CF3MA, and CF8A, they are not recommended for service at temperatures above 800 F [425 C]

<sup>B</sup> ST = to be solution treated

<sup>C</sup> Refer to original specification for additional information on heat treatment requirements

<sup>D</sup> When ICI test bars are used in tensile tests as provided for in this specification, the gage length to reduced section diameter ratio shall be 4:1

<sup>E</sup> Because of embrittlement phases of Grade CD4MCu is not recommended for service at temperatures above 600 F [316 C]

<sup>F</sup> Grade CF8C shall have a columbium content of not less than 8 times the carbon content but not over 1.00%

<sup>G</sup> Grade CF10MC shall have a columbium content of not less than 10 times the carbon content but not over 1.20%

<sup>H</sup> % Cr + 3.3% Mo + 16% N ≥ 40

## ASTM A 447/A 447M – 93 STEEL CASTINGS, CHROMIUM-NICKEL-IRON ALLOY (25-12 CLASS), FOR HIGH-TEMPERATURE SERVICE

This specification covers iron-base, heat-resisting alloy castings of the 25% chromium, 12% nickel class, intended for structural elements, containers, and supports in electric furnaces, petroleum still tube supports, and for similar applications up to 2000 F [1095 C]. The purchaser should inform the manufacturer when the service temperatures are to exceed 1800 F [980 C].

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment <sub>A</sub>	Tensile Strength <sub>BC</sub>		Yield Strength		Elong	Red A	Other Tests <sub>DE</sub> Magnetic Permeability	C	Mn	P	S	Si	Ni <sub>F</sub>	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
I	as cast	80	550				9	1.70	0.20					10.00	23.00		N 0.20 Fe <sub>G</sub>
J93303									0.45	2.50	0.05	0.05	1.75	14.00	28.00		
II	as cast	80	550				4	1.05	0.20					10.00	23.00		N 0.20 Fe <sub>G</sub>
J93303									0.45	2.50	0.05	0.05	1.75	14.00	28.00		

<sup>A</sup> As agreed upon by manufacturer and purchaser

<sup>B</sup> Properties after aging

<sup>C</sup> Short term, high temperature tensile property requirements for the grades are as follows: Type I is to be agreed upon by manufacturer and producer, and Type II is to have a minimum of 20 ksi [140 MPa] tensile strength and a minimum elongation of 8%

<sup>D</sup> The stress rupture test for the grades is as follows with the tensile stress being sustained for at least 16h: Type I at 5 ksi [34 MPa] and Type II at 8 ksi [55 MPa]

<sup>E</sup> Refer to original specification for details; note that out of the four tests (tension after aging, magnetic permeability, stress rupture, and short time high-temperature) the purchaser shall specify no more than two tests

<sup>F</sup> Commercial nickel usually carries a small amount of cobalt, and within the usual limits cobalt shall be counted as nickel

<sup>G</sup> The manufacturer and purchaser may agree upon allowable limits of iron and other elements

## ASTM A 494/A 494M – 98 CASTINGS, NICKEL AND NICKEL ALLOY

This specification covers nickel, nickel-copper, nickel-copper-silicon, nickel-molybdenum, nickel chromium, and nickel-molybdenum-chromium alloy castings for corrosion resistant service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong <sub>E</sub>	Red A	Other Tests Hardness (HBN)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
CZ-100	as cast	50	345	18	125	10.0			1.00	1.50	0.03	0.03	2.00	95			Fe 3.0 Cu 1.25
N02100																	Cu 26.0
M-35-1 <sub>A</sub>	as cast	65	450	25	170	25.0			0.35	1.50	0.03	0.03	1.25	bal.			Cu 33.0 Fe 3.5 Cb 0.5
N24135																	Cu 26.0
M-35-2	as cast	65	450	30	205	25.0			0.35	1.50	0.03	0.03	2.00	bal.			Cu 33.0 Fe 3.5 Cb 0.5
N04020																	Cu 27.0
M-30H	as cast	100	690	60	415	10		243	0.30	1.50	0.03	0.03	2.7	bal.			Cu 33.0 Fe 3.5
N24030								294 <sub>B</sub>					3.7				Cu 27.0
M-25S <sub>D</sub>	as cast or age-							c					3.5	bal.			Cu 33.0 Fe 3.5
N24025	hardened <sub>F</sub>								0.25	1.50	0.03	0.03	4.5				

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment	Tensile Strength		Yield Strength		Elong <sub>E</sub>	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
And UNS		ksi	MPa	ksi	MPa	%	%	Hardness (HBN)									
M-30C <sub>A</sub> N24130	as cast	65	450	32.5	225	25		125 150 <sub>B</sub>	0.30	1.50	0.03	0.03	1.0 2.0	bal.			Cu 26.0 Cb 1.0 Cu 33.0 Cb 3.0 Fe 3.5
N-12MV N30012	ST 2000F [1095]	76	525	40	275	6.0			0.12	1.00	0.040	0.030	1.00	bal.	1.00	26.0 30.0	Fe 4.0 V 0.20 Fe 6.0 V 0.60
N-7M N30007	ST 2000F [1095]	76	525	40	275	20.0			0.07	1.00	0.040	0.030	1.00	bal.	1.0	30.0 33.0	Fe 3.0
CY-40 N06040	as cast or ST 1900F [1040C]	70	485	28	195	30.0			0.40	1.50	0.03	0.03	3.00	bal.	14.0 17.0		Fe 11.0
CW-12MW N30002	ST 2150F [1180C]	72	495	40	275	4.0			0.12	1.00	0.040	0.030	1.00	bal.	15.5 17.5	16.0 18.0	Fe 4.5 V 0.20 W 3.75 Fe 7.5 V 0.40 W 5.25
CW-6M N30107	ST 2150F [1180C]	72	495	40	275	25.0			0.07	1.00	0.040	0.030	1.00	bal.	17.0 20.0	17.0 20.0	Fe 3.0
CW-2M N26455	ST 2150F [1180C]	72	495	40	275	20.0			0.02	1.00	0.03	0.03	0.80	bal.	15.0 17.5	15.0 17.5	Fe 2.0 W 1.0
CW-6MC N26625	ST 2150F [1180C]	70	485	40	275	25.0			0.06	1.00	0.015	0.015	1.00	bal.	20.0 23.0	8.0 10.0	Cb 3.15 Cb 4.50 Fe 5.0
CY5SnBiM N26055	as cast								0.05	1.5	0.03	0.03	0.5	bal.	11.0 14.0	2.0 3.5	Bi 3.0 Sn 3.0 Bi 5.0 Sn 5.0 Fe 2.0
CX2MW N26022	ST 2200F [1205C]	80	550	45	280	30.0			0.02	1.00	0.025	0.025	0.08	bal.	20.0 22.5	12.5 14.5	Fe 2.0 W 2.5 Fe 6.0 W 3.5 V 0.35
CU5MCuC N28820	ST 2100F [1150C] <sub>F</sub>	75	520	35	240	20.0			0.050	1.0	0.030	0.030	1.0	38.0 44.0	19.5 23.5	2.5 3.5	Cu 1.50 Cb 0.60 Cu 3.50 Cb 1.20 Fe bal.

<sub>A</sub> When weldability is needed, Grade M-35-1 or M-30C should be ordered

<sub>B</sub> For information only

<sub>C</sub> Minimum age-hardened 300 BHN

<sub>D</sub> M-25S, while machinable in the "as cast" condition is capable of being solution treated for improved machinability; it may be subsequently age-hardened to the specified hardness and finished machined or ground

<sub>E</sub> When ICI test bars are used in tensile tests as provided for per Specification A 732/A 732M, the gage length to reduced section diameter ratio shall be 4:1

<sub>F</sub> Refer to original specification for additional information on heat treatment requirements

## ASTM A 560/A 560M – 93 CASTINGS, CHROMIUM-NICKEL ALLOY

This specification covers chromium-nickel alloy castings intended for heat resisting and elevated-temperature corrosion applications such as structural members, containers, supports, hangers, spacers and the like in corrosive environments up to 2000 F [1090 C].

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other <sub>D</sub>
		ksi	MPa	ksi	MPa	%	%										
50 Cr-50 Ni R20500	as cast	80	550	50	340	5		<i>B</i>	0.10	0.30	0.02	0.02	1.00	bal.	48.0 52.0		N 0.30 Fe 1.0 Ti 0.50 Al 0.25
60 Cr-40 Ni R20600	as cast	110	760	85	590			<i>C</i>	0.10	0.30	0.02	0.02	1.00	bal.	58.0 62.0		N 0.30 Fe 1.0 Ti 0.50 Al 0.25
50 Cr-50 Ni-Cb R20501	as cast	80	550	50	345	5			0.10	0.30	0.02	0.02	0.50	bal.	47.0 52.0		Cb 1.4 Cb 1.7 N 0.16 N+C 0.20 Fe 1.00 Ti 0.50 Al 0.25

<sub>A</sub> Heat treatment as agreed upon by manufacturer and purchaser

<sub>B</sub> Impact, unnotched Charpy, 50 ft-lbs [78 J] minimum

<sub>C</sub> Impact, unnotched Charpy, 50 ft-lbs [78 J] minimum

<sub>D</sub> The total of the Cr, Ni, and Cb contents must exceed 97.5%

This specification covers iron-chromium and iron-chromium-nickel-alloy castings for general corrosion-resistant application. The grades covered by this specification represent types of alloy castings suitable for broad ranges of application which are intended for a wide variety of corrosion environments.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong <sub>B</sub> %	Red A %	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	Mpa	Ksi	Mpa												
CF-8 J92600	ST 1900F [1040C]	70 <sub>E</sub>	485 <sub>E</sub>	30 <sub>E</sub>	205 <sub>E</sub>	35		<i>B</i>	0.08	1.50	0.04	0.04	2.00	8.0 11.0	18.0 21.0		
CG-12 J93001	ST 1900F [1040C]	70	485	28	195	35			0.12	1.50	0.04	0.04	2.00	10.0 13.0	20.0 23.0		
CF-20 J92602	ST 1900F [1040C]	70	485	30	205	30			0.20	1.50	0.04	0.04	2.00	8.0 11.0	18.0 21.0		
CF-8M J92900	ST 1900F [1040C]	70	485	30	205	30		<i>B</i>	0.08	1.50	0.04	0.04	2.00	9.0 12.0	18.0 21.0	2.0 3.0	
CF-8C J92710	ST 1900F [1040C]	70	485	30	205	30		<i>B</i>	0.08	1.50	0.04	0.04	2.00	9.0 12.00	18.0 21.0		Cb <sub>G</sub>
CF-16F J92701	ST 1900F [1040C]	70	485	30	205	25			0.16	1.50	0.17	0.04	2.00	9.0 12.00	18.0 21.0	1.50	Se 0.2
CF-16Fa	ST 1900F [1090C]	70	485	30	205	25			0.16	1.50	0.04	0.20 0.40	2.00	9 12	18.0 21.0	0.4 0.8	Se 0.35
CH-10	ST 1900F [1090C]	70	485	30	205	30			0.10	1.50	0.04	0.04	2.00	12.0 15.0	22.0 26.0		
CH-20 J93402	ST 1900F [1040C]	70	485	30	205	30			0.20	1.50	0.04	0.04	2.00	12.0 15.0	22.0 26.0		
CK-20 J94202	ST 1900F [1040C]	65	450	28	195	30			0.20	2.00	0.04	0.04	2.00	19.0 22.0	23.0 27.0		
CE-30 J93423	ST 1900F [1040C]	80	550	40	275	10			0.30	1.50	0.04	0.04	2.00	8.0 11.0	26.0 30.0		
CA-15 J91150	NT or A	90	620	65	450	18	30	<i>C</i>	0.15	1.00	0.04	0.04	1.50	1.00	11.5 14.0	0.50	
CA-15M J91151	NT or A	90	620	65	450	18	30	<i>C</i>	0.15	1.00	0.040	0.040	0.65	1.0	11.5 14.0	0.15 1.00	
CB-30 J91803	N or A	65	450	30	205			<i>C</i>	0.30	1.00	0.04	0.04	1.50	2.00	18.0 21.0		Cu <sub>H</sub>
CC-50 J92615	N or A	55	380					<i>C</i>	0.50	1.00	0.04	0.04	1.50	4.00	26.0 30.0		
CA-40 J91153	NT or A	100	690	70	485	15	25	<i>C</i>	0.20 0.40	1.00	0.04	0.04	1.50	1.0	11.5 14.0	0.50	
CA-40F J91154	NT or A	100	690	70	485	12		<i>C</i>	0.20 0.40	1.00	0.04	0.20 0.40	1.50	1.0	11.5 14.0	0.5	
CF-3 J92500	as cast or ST	70	485	30	205	35		<i>B</i>	0.03	1.50	0.04	0.04	2.00	8.0 12.0	17.0 21.0		
CF10SMnN J92972	ST 1950F [1065C]	85	585	42	290	30			7.0 9.0		0.060	0.030	3.50 4.50	8.0 9.0	16.0 18.0		N 0.08 N 0.18
CF-3M	as cast or ST	70	485	30	205	30		<i>B</i>	0.03	1.50	0.04	0.04	1.50	9.0 13.0	17.0 21.0	2.0 3.0	
CF3MN J92804	as cast or ST	75	515	37	255	35			0.03	1.50	0.040	0.040	1.50	9.0 13.0	17.0 21.0		N 0.10 N 0.20

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong <sub>B</sub> %	Red A %	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	Mpa	Ksi	Mpa												
CG6MMN	ST 2050F [1120C]	85	585	42	290	30			0.006	4.0	0.04	0.03	1.00	11.5	20.5	1.50	Cb 0.10 V 0.10 N 0.20
CG-3M J92999	ST 1900F [1040C]	75	515	35	240	25		<i>B</i>	0.03	6.0	0.04	0.04	1.50	13.5	23.5	3.00	Cb 0.30 V 0.30 N 0.40
CG-8M J93000	ST 1900F [1040C]	75	520	35	240	25			0.08	1.50	0.04	0.04	1.50	9.0	18.0	3.0	
CN3M J94652	ST 2150F [1175C]	63	435	25	170	30			0.03	1.50	0.04	0.04	1.50	9.0	18.0	3.0	
CN-3MN J94651	ST 2100F [1150C]	80	550	38	260	35			0.03	2.0	0.03	0.03	1.0	23.0	20.0	4.5	
CN-7M	ST 2050F [1120C]	62	425	25	170	35			0.07	2.0	0.040	0.010	1.00	27.0	22.0	5.5	
CN-7MS	ST 2100F [1150C]	70	485	30	205	35			0.03	2.0	0.04	0.04	1.50	23.5	20.0	6.0	N 0.18
CA-6NM J91540	NT 1050F [565C]	110	755	80	550	15	35	<i>C</i>	0.07	1.50	0.04	0.04	1.50	15.5	22.0	7.0	N 0.26 Cu 0.75
CA-6N J91650	NT 1500F [815C]	140	965	135	930	15	50		0.07	1.00	0.04	0.03	3.50	27.5	19.0	2.0	Cu 3.0
CA-28MWV <sub>F</sub> J91422	QT or A	140	965	110	760	10	24	<i>C</i>	0.06	1.00	0.04	0.03	1.00	30.5	22.0	3.0	Cu 4.0
CK-3MCuN J93254	ST 2100F [1150C]	80	550	38	260	35			0.06	0.50	0.02	0.02	1.00	22.0	18.0	2.5	Cu 1.5
CK-35MN	ST 2100-2190F [1150-1200C]	83	570	41	280	35			0.06	0.50	0.02	0.02	1.00	25.0	20.0	3.0	Cu 2.0
CB-6 J91804	NT 1110F [595C]	115	790	85	580	16	35		0.20	1.00	0.030	0.030	1.0	3.5	11.5	0.40	
									0.28	1.00	0.030	0.030	1.0	4.5	14.0	1.0	
									0.025	1.20	0.045	0.010	1.00	6.0	10.5		
									0.035	2.0	0.035	0.020	1.00	8.0	12.5		
									0.035	2.0	0.035	0.020	1.00	17.5	19.5	6.0	V 0.20 W 0.90
									0.06	1.00	0.04	0.03	1.00	19.5	20.5	7.0	V 0.30 W 1.25
									0.06	1.00	0.04	0.03	1.00	20.0	22.0	6.0	N 0.180 Cu 0.50
									0.06	1.00	0.04	0.03	1.00	22.0	24.0	6.8	N 0.240 Cu 1.0
									0.06	1.00	0.04	0.03	1.00	3.5	15.5		N 0.21
									0.06	1.00	0.04	0.03	1.00	5.5	17.5	0.5	N 0.32 Cu 0.40

<sub>A</sub> Refer to original specification for additional heat treatment information

<sub>B</sub> Supplementary intergranular corrosion test if specified by the customer

<sub>C</sub> Supplementary requirement for hardness tests when desired by the purchaser

<sub>D</sub> When ICI test bars are used in tensile tests as provided for in this specification, the gage length to reduced section diameter ratio shall be 4:1

<sub>E</sub> For low ferrite or nonmagnetic castings of this grade, the following values shall apply: tensile strength, min, 65 ksi [450 MPa]; yield point, min, 28 ksi [195 MPa]

<sub>F</sub> These mechanical properties apply only when heat-treatment (1) has been used

<sub>G</sub> Grade CF-8C shall have a columbium content of not less than 8 times the carbon content and not more than 1.0% - if a columbium plus tantalum alloy in the approximate Cb:Ta ratio of 3:1 is used for stabilizing this grade, the total columbium-plus-tantalum content shall not be less than nine times the carbon content and shall not exceed 1.1%

<sub>H</sub> For Grade CB-30 a copper content of 0.90 to 1.20% is optional

## ASTM A 744/A 744M – 98 CASTINGS, IRON-CHROMIUM-NICKEL, CORROSION RESISTANT, FOR SEVERE SERVICE

This specification covers iron-chromium-nickel-alloy, stainless steel castings intended for particularly corrosive applications.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)						CHEMICAL COMPOSITION, % (maximum percent unless range given)									
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong <sub>B</sub> %	Red A %	Other Tests <sub>C</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CF-8 J92600	ST 1900F [1040C]	70 <sub>E</sub>	485 <sub>E</sub>	30 <sub>E</sub>	205 <sub>E</sub>	35			0.08	1.50	0.04	0.04	2.00	8.0	18.0		
CF-8M J92900	ST 1900F [1040C] <sub>D</sub>	70	485	30	205	30			0.08	1.50	0.04	0.04	2.00	11.0	21.0		
CF-8C J92710	ST 1900F [1040C]	70	485	30	205	30			0.08	1.50	0.04	0.04	2.00	9.0	18.0	2.0	
									0.08	1.50	0.04	0.04	2.00	12.0	21.0	3.0	
									0.08	1.50	0.04	0.04	2.00	9.0	18.0		Cb <sub>F</sub>
									0.08	1.50	0.04	0.04	2.00	12.0	21.0		

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong <sub>B</sub> %	Red A %	Other Tests <sub>C</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CF-3 J92500	ST 1900F [1040C]	70	485	30	205	35			0.03 <sub>G</sub>	1.50	0.04	0.04	2.00	8.0 12.0	17.0 21.0		
CF-3M J92800	ST 1900F [1040C] <sub>D</sub>	70	485	30	205	30			0.03 <sub>G</sub>	1.50	0.04	0.04	1.50	9.0 13.0	17.0 21.0	2.0 3.0	
CG-3M J92999	ST 1900F [1040C]	75	515	35	240	25			0.03	1.50	0.04	0.04	1.50	9.0 13.0	18.0 21.0	3.0 4.0	
CG-8M J93000	ST 1900F [1040C] <sub>D</sub>	75	520	35	240	25			0.08	1.50	0.04	0.04	1.50	9.0 13.0	18.0 21.0	3.0 4.0	
CN-7M	ST 2050F [1120C]	62	425	25	170	35			0.04	1.50	0.04	0.04	1.50	27.5 30.5	19.0 22.0	2.0 3.0	Cu 3.0 Cu 4.0
CN-7MS J94650	ST 2100F[1150C]	70	485	30	205	35			0.07	1.00	0.04	0.03	2.50 3.50	22.0 25.0	18.0 20.0	2.5 3.0	Cu 1.5 Cu 2.0
CN-3MN J94651	ST 2100F[1150C]	80	550	38	260	35			0.03	2.00	0.040	0.010	1.00	23.5 25.5	20.0 22.0	6.00 7.00	N 0.18 N 0.26 Cu 0.75
CD-4Mcu J93370	ST 1900F [1040C]	100	690	70	485	16			0.04	1.00	0.04	0.04	1.00	4.75 6.00	24.5 26.5	1.75 2.25	Cu 2.75 Cu 3.25
CK3MCuN J93254	ST 2100F [1150C]	80	550	38	260	35			0.025	1.20	0.045	0.010	1.0	17.5 19.5	19.5 20.5	6.0 7.0	N 0.180 Cu 0.50 N 0.240 Cu 1.0

<sub>A</sub> Refer to original specification for additional heat treatment information

<sub>B</sub> When ICI test bars are used in tensile tests as provided for in this specification, the gage length to reduced section diameter ratio shall be 4:1

<sub>C</sub> Supplementary intergranular corrosion test if specified by the customer

<sub>D</sub> For optimum tensile strength, ductility and corrosion resistance, the solution annealing temperature should be in excess of 1900 F [1040 C]

<sub>E</sub> For low ferrite or nonmagnetic castings of this grade, the following values shall apply: tensile strength, min, 65 ksi [450 MPa]; yield point, min, 28 ksi [195 MPa]

<sub>F</sub> Grade CF-8C shall have a columbium content of not less than 8 times the carbon content and not more than 1.0% - if a columbium-plus-tantalum alloy in the approximate Cb:Ta ration of 3:1 is used for stabilizing this grade, the total columbium-plus-tantalum content shall not be less than 9 times the carbon content and shall not exceed 1.1%

<sub>G</sub> For purposes of determining conformance with this specification, the observed or calculated value for carbon content shall be rounded to the nearest 0.01% in accordance with rounding method of Recommended Practice E29

## ASTM A 747/A 747M – 93

## STEEL CASTINGS, STAINLESS, PRECIPITATION HARDENING

This specification covers iron-chromium-nickel-copper corrosion-resistant steel castings, capable of being strengthened by precipitation hardening heat treatment.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Hardness (HBN)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CB7Cu-1 J92180	H-900 <sub>A</sub>	170	1170	145	1000	5		375	0.07	0.70	0.035	0.03	1.00	3.60 4.60	15.50 17.70		Cu 2.50 Cb 0.15 <sub>B</sub> Cu 3.20 Cb 0.35 <sub>B</sub> N 0.05 <sub>C</sub>
	H-925 <sub>A</sub>	175	1205	150	1035	5		375									
	H-1025 <sub>A</sub>	150	1035	140	965	9		311									
	H-1075 <sub>A</sub>	145	1000	115	795	9		277									
	H-1100 <sub>A</sub>	135	930	110	760	9		269									
	H-1150 <sub>A</sub>	125	860	97	670	10		269									

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%	Hardness (HBN)									
CB7Cu-2 J92110	H-1150M							310									
	H-1150DBL							310									
	H-900 <sub>A</sub>	170	1170	145	1000	5		375	0.07	0.70	0.035	0.03	1.00	4.50	14.0		Cu 2.50 Cb 0.15 <sub>B</sub> Cu 3.20 Cb 0.35 <sub>B</sub> N 0.05 <sub>C</sub>
	H-925 <sub>A</sub>	175	1205	150	1035	5		375									
	H-1025 <sub>A</sub>	150	1035	140	965	9		311									
	H-1075 <sub>A</sub>	145	1000	115	795	9		277									
	H-1100 <sub>A</sub>	135	930	110	760	9		269									
	H-1150 <sub>A</sub>	125	860	97	670	10		269									
	H-1150M							310									
	H-1150DBL							310									

<sub>A</sub> All mechanical properties are supplementary and are not required unless stipulated by the customer, see original specification for additional information

<sub>B</sub> When the H900 condition is ordered, the minimum Cb shall not apply

<sub>C</sub> To be determined and reported when specified by the order or contract

ASTM A 890/A 890M – 97

CASTINGS, IRON-CHROMIUM-NICKEL-MOLYBDENUM CORROSION-RESISTANT, DUPLEX (AUSTENITIC/FERRITIC) FOR GENERAL APPLICATION

This specification covers a group of cast duplex stainless steels (austenitic/ferritic).

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES <sub>B</sub> (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	Mpa												
1A	heat to 1900F	100	690	70	485	16								4.75	24.5	1.75	Cu 2.75
J93370	[1040C]								0.04	1.00	0.040	0.040	1.00	6.00	26.5	2.25	Cu 3.25
1B	heat to 1900F	100	690	70	485	16								4.7	24.5	1.7	Cu 2.7 N 0.10
J93372	[1040C]								0.04	1.0	0.04	0.04	1.0	6.0	26.5	2.3	Cu 3.3 N 0.25
2A	heat to 2050F	95	655	65	450	25								8.00	22.5	3.00	N 0.10
J93345	[1120C]								0.08	1.00	0.04	0.04	1.50	11.00	25.5	4.50	N 0.30
3A	heat to 1950F	95	655	65	450	25								4.00	24.0	1.75	N 0.15
J93371	[1070C]								0.06	1.00	0.040	0.040	1.00	6.00	27.0	2.50	N 0.25
4A	heat to 2050F	90	620	60	415	25								4.5	21.0	2.5	N 0.10
J92205	[1120C]								0.03	1.50	0.04	0.020	1.00	6.5	23.5	3.5	N 0.30 Cu 1.00
5A	heat to 2050F	100	690	75	515	18								6.0	24.0	4.0	N 0.10
J93404	[1120C]								0.03	1.50	0.04	0.04	1.00	8.0	26.0	5.0	N 0.30
6A	heat to 2010F	100	690	65	450	25								6.5	24.0	3.0	Cu 0.5 N 0.20 W 0.5
J93380	[1100C]								0.03	1.00	0.030	0.025	1.00	8.5	26.0	4.0	Cu 1.0 N 0.30 W 1.0

<sub>A</sub> See original specification for additional details on heat treatment

<sub>B</sub> Tensile requirement is a supplementary requirement, see original specification for additional details

# CASTINGS, IRON-NICKEL-CHROMIUM AND NICKEL ALLOYS, SPECIALLY CONTROLLED FOR PRESSURE RETAINING PARTS FOR CORROSIVE SERVICE

This specification covers iron-nickel-chromium and nickel alloy castings specially processed with restricted melt practices, weldability testing and nondestructive examination (NDE) requirements.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>B</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
CW-2M	heat to 2250F [1232C]	72	495	40	275	20.0			0.020	1.00	0.030	0.015	0.80	bal.	15.0 17.5	15.0 17.5	Fe 2.00 W 1.00

<sub>A</sub> See original specification for additional details on heat treatment

<sub>B</sub> See original specification for additional details on Nondestructive Examination Requirements

# CORROSION-RESISTANT CAST STEELS FOR GENERAL APPLICATIONS

This International Standard specifies cast steels for general corrosion-resistant applications. The grades covered by this International Standard represent types of alloy steel castings suitable for broad ranges of application which are intended for a wide variety of corrosion applications.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)								CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests		C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	Mpa	ksi	Mpa	%	%	Impact (J)	Ruling Thickness (mm)									
GX 12 Cr 12	A [950-1050C] & T [650-750C]		620		450	14		20	150	0.15	0.8	0.035	0.025	0.8	1.0	11.5	0.5	
GX 8 CrNiMo 12 1	A [1000-1050C] & T [620-720C]		590		440	15		27	300	0.10	0.8	0.035	0.025	0.8	0.8	11.5	0.2	
GX 4 CrNi 12 4 (QT 1)	A [1000-1100C] & T [570-620C]		750		550	15		45	300	0.06	1.5	0.035	0.025	1.0	3.5	11.5	1.0	
GX 4 CrNi 12 4 (QT 2)	A [1000-1100C] & T [500-530C]		900		830	12		35	300	0.06	1.5	0.035	0.025	1.0	3.5	11.5	1.0	
GX 4 CrNiMo 16 5 1	A [1020-1070C] & T [580-630C]		760		540	15		60	300	0.06	0.8	0.035	0.025	0.8	4.0	15.0	0.7	
GX 2 CrNi 18 10	ST [1050C]		440		180	30		80	150	0.03	1.5	0.040	0.030	1.5	9.0	17.0	1.5	
GX 2 CrNiN 18 10	ST [1050C]		510		230	30		80	150	0.03	1.5	0.040	0.030	1.5	9.0	17.0		N 0.10
GX 5 CrNi 19 9	ST [1050C]		440		180	30		60	150	0.03	1.5	0.040	0.030	1.5	8.0	18.0		N 0.20
GX 6 CrNiNb 19 10	ST [1050C]		440		180	25		40	150	0.07	1.5	0.040	0.030	1.5	11.0	21.0		
GX 2 CrNiMo 19 11 2	ST [1080C]		440		180	30		80	150	0.08	1.5	0.040	0.030	1.5	9.0	17.0	2.0	
GX 2 CrNiMoN 19 11 2	ST [1080C]		510		230	30		80	150	0.03	1.5	0.040	0.030	1.5	9.0	17.0	2.0	N 0.10
GX 5 CrNiMo 19 11 2	ST [1080C]		440		180	30		60	150	0.03	1.5	0.040	0.030	1.5	9.0	17.0	2.0	N 0.20
GX 6 CrNiMoNb 19 11 2	ST [1080C]		440		180	25		40	150	0.07	1.5	0.040	0.030	1.5	9.0	17.0	2.0	
GX 2 CrNiMo 19 11 3	ST [1120C]		440		180	30		80	150	0.08	1.5	0.040	0.030	1.5	9.0	17.0	3.0	
									150	0.03	1.5	0.040	0.030	1.5	12.0	20.0	3.5	



GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)								CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sup>A</sup>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests		C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	Mpa	ksi	Mpa			Impact (J)	Ruling Thickness (mm)									
GX 2 CrNiMoN 19 11 3	ST [1120C]		510		230	30		80										N 0.10
GX 5 CrNiMo 19 11 3	ST [1120C]		440		180	30		60		0.03	1.5	0.040	0.030	1.5	12.0	20.0	3.5	N 0.20
GX 2 CrNiCuMoN 26 5 3 3	ST [1120C]		650		450	18		50		0.07	1.5	0.040	0.030	1.5	12.0	20.0	3.5	
GX 2 CrNiMoN 26 5 3	ST [1120C]		650		450	18		50		0.03	1.5	0.035	0.025	1.0	4.5	25.0	2.5	Cu 2.5 N 0.12
															6.5	27.0	3.5	Cu 3.5 N 0.25
															4.5	25.0	2.5	N 0.12
										0.03	1.5	0.035	0.025	1.0	6.5	27.0	3.5	N 0.25

<sup>A</sup> See original specifications for additional information

## ISO DIS 11973

## HEAT-RESISTANT CAST STEELS FOR GENERAL PURPOSES

This International Standard covers cast steels for heat resistant service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)								CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests		C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa			Hardness (HBN)	Use Temp. (C) <sub>c</sub>									
GX 30 CrSi 7	A [800-850C] or as cast								750	0.20	0.50			1.00		6.00		
GX 40 CrSi 13	A [800-850C]									0.35	1.00	0.040	0.040	2.50	0.50	8.00	0.50	
GX 40 CrSi 17	A [800-850C]							300 <sub>B</sub>	850	0.30	0.50			1.00		12.00		
										0.50	1.00	0.040	0.030	2.50	1.00	14.00	0.50	
GX 40 CrSi 24	A [800-850C]							300 <sub>B</sub>	900	0.30	0.50			1.00		16.00		
										0.50	1.00	0.040	0.030	2.50	1.00	19.00	0.50	
GX 40 CrSi 28	A [800-850C]							300 <sub>B</sub>	1050	0.30	0.50			1.00		23.00		
										0.50	1.00	0.040	0.030	2.50	1.00	26.00	0.50	
GX 130 CrSi 29	A [800-850C]							320 <sub>B</sub>	1100	0.30	0.50			1.00		27.00		
										0.50	1.00	0.040	0.030	2.50	1.00	30.00	0.50	
								400 <sub>B</sub>	1100	1.20	0.50			1.00		27.00		
										1.40	1.00	0.040	0.030	2.50	1.00	30.00	0.50	
GX 25 CrNiSi 18-9	as cast		450		230	15			900	0.15				1.00	8.00	17.00		
										0.35	2.00	0.040	0.030	2.50	10.00	19.00	0.50	
GX 25 CrNiSi 20-14	as cast		450		230	10			900	0.15				1.00	13.00	19.00		
										0.35	2.00	0.040	0.030	2.50	15.00	21.00	0.50	
GX 40 CrNiSi 22-10	as cast		450		230	8			950	0.30				1.00	9.00	21.00		
										0.50	2.00	0.040	0.030	2.50	11.00	23.00	0.50	
GX 40 CrNiSiNb 24-24	as cast		400		220	4			1050	0.25				1.00	23.00	23.00		Nb 1.20
										0.50	2.00	0.040	0.030	2.50	25.00	25.00	0.50	Nb 1.80
GX 40 CrNiSi 25-12	as cast		450		220	6			1050	0.30				1.00	11.00	24.00		
										0.50	2.00	0.040	0.030	2.50	14.00	27.00	0.50	
GX 40 CrNiSi 25-20	as cast		450		220	6			1100	0.30				1.00	19.00	24.00		
										0.50	2.00	0.040	0.030	2.50	22.00	27.00	0.50	
GX 40 CrNiSi 27-4	as cast		400		250	3				0.30				1.00	3.00	25.00		
								400	1100	0.50	1.50	0.040	0.030	2.50	6.00	28.00	0.50	
GX 40 NiCrCo 20-20-20	as cast		400		320	6			1150	0.35					18.00	19.00	2.50	Co 18.00 W 2.00
										0.60	2.00	0.040	0.030	1.00	22.00	22.00	3.00	Co 22.00 W 3.00
GX 10 NiCrNb 31-20	as cast		440		170	20			1000	0.05					30.00	19.00		Nb 0.80
										0.12	1.20	0.040	0.030	1.20	34.00	23.00	0.50	Nb 1.50
GX 40 NiCrSi 35-17	as cast		420		220	6				0.30				1.00	34.00	16.00		
									980	0.50	2.00	0.040	0.030	2.50	36.00	18.00	0.50	

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Hardness (HBN) Use Temp. (C) <sub>c</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
GX 40 NiCrSi 35-26	as cast		440		220	6			0.30				1.00	33.00	24.00		
GX 40 NiCrSiNb 35-26	as cast		440		220	4		1050	0.50	2.00	0.040	0.030	2.50	36.00	27.00	0.50	
GX 40 NiCrSi 38-19	as cast		420		220	6			0.30				1.00	36.00	18.00		
GX 40 NiCrSiNb 38-19	as cast		420		220	4		1050	0.50	2.00	0.040	0.030	2.50	39.00	21.00	0.50	
GX 45 NiCrWSi 48-28-5	as cast		400		220	3			0.35				1.00	47.00	27.00		
GX 10 NiCrNb 50-50	as cast		540		230	8		1200	0.55	1.50	0.040	0.030	2.50	50.00	30.00		
GX 50 NiCr 52-19	as cast		440		220	5			0.40				0.50	50.00	16.00		
GX 50 NiCr 65-15	as cast		400		200	3		1100	0.60	1.50	0.040	0.030	2.00	55.00	21.00	0.50	
GX 45 NiCrCoW 35-25-15-5	as cast		480		270	5			0.35				0.50	64.00	13.00		
GX 30 CoCr 50-28	as cast		A		A	A		1100	0.65	1.30	0.040	0.030	2.00	69.00	19.00		
								1200	0.44				1.00	33.00	24.00		W 4.00 Co 14.0
									0.48	2.00	0.040	0.030	2.00	37.00	26.00		W 6.00 Co 16.0
													1.00	25.00			Co 48.0
													1.00	30.00	0.50		Co 52.0 Fe 20.0

<sub>A</sub> Properties as agreed upon by manufacturer and purchaser

<sub>B</sub> Maximum hardness in annealed condition – castings may also be supplied in the “as cast” condition, in which case hardness limits will not apply

<sub>C</sub> Maximum use temperature depends upon the actual use conditions and these values are being given only to aid the user; these are given for oxidising environments, the actual alloy composition will also affect performance

## ISO 12725

## NICKEL AND NICKEL ALLOY CASTINGS

This International Standard specifies requirements for nickel and nickel alloy castings. The grades covered represent types of alloys suitable for a broad range of application in a wide variety of corrosive and high temperature environments.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Hardness (HBN)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
C-Ni99, HC	as cast		345		125	10								95.0			
C-NiCu30Si	as cast		545		205	25			1.00	1.50	0.030	0.030	2.00	bal.			Cu 1.25 Fe 3.0
C-NiCu30	as cast		650		170	25			0.35	1.50	0.030	0.030	2.00	bal.			Cu 26.0
C-NiCu30Si3	as cast		450		170	25			0.35	1.50	0.030	0.030	1.25	bal.			Cu 33.0 Fe 3.5 Nb 0.5
C-NiCu30Nb2Si2	as cast		690		415	10			0.30	1.50	0.030	0.030	2.7	bal.			Cu 26.0
C-NiMo31	heat to [1095C] WQ		890		225	25			0.30	1.50	0.030	0.030	3.7	bal.			Cu 33.0 Fe 3.5
C-NiMo30Fe5	heat to [1095C] WQ		450		225	25			0.30	1.50	0.030	0.030	1.0	bal.			Cu 26.0 Nb 1.0
C-NiCr22Fe20Mo7Cu2	heat to [1095C] WQ		525		275	6			0.03	1.00	0.030	0.030	2.0	bal.		30.0	Cu 33.0 Nb 3.0 Fe 3.5
			725		275	20			0.05	1.00	0.030	0.030	1.00	bal.	1.0	33.0	Fe 3.0
			725		220	30			0.05	1.00	0.030	0.030	1.00	bal.	1.0	33.0	Fe 4.0 V 0.20
			550		750				0.02	1.00	0.025	0.030	1.00	bal.	21.5	6.0	Fe 6.0 V 0.60
															23.5	8.0	Cu 1.5 Fe 18.0
																	Cu 2.5 Fe 21.0 W 1.50 Co 5.0 Nb+Ta 0.5

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%	Hardness (HBN)									
C-NiCr22Mo9Nb4	heat to [1175C] WQ		485		275	25			0.06	1.00	0.030	0.030	1.00	bal.	20.0	8.0	Nb 3.2
			685														Nb 4.5 Fe 5.0
C-NiCr16Mo16	heat to [1175C] WQ		495		275	20			0.02	1.00	0.030	0.030	0.80	bal.	15.0	15.0	
			695												17.5	17.5	Fe 2.0 W 1.00
C-NiMo17Cr16Fe6W4	heat to [1175C] WQ		495		275	4			0.06	1.00	0.030	0.030	1.00	bal.	15.5	16.0	Fe 4.5 W 3.8 V 0.20
			695												17.5	18.0	Fe 7.5 W 5.3 V 0.40
C-NiCr21Mo14Fe4W3	heat to [1205C] WQ		550		280	30			0.02	1.00	0.030	0.030	1.00	bal.	20.0	12.5	Fe 2.0 W 2.5
															22.5	14.5	Fe 6.0 W 3.5 V 0.35
C-NiCr18Mo18	heat to [1175C] WQ		495		275	25			0.03	1.00	0.030	0.030	1.00	bal.	17.0	17.0	
			695												20.0	20.0	Fe 3.0
C-NiCr15Fe	as cast, heat to [1040C] WQ		485		195	30			0.40	1.50	0.030	0.030	3.00	bal.	14.0		
			685												17.0		Fe 11.0
C-NiFe30Cr20Mo3CuNb	heat to [930-980C] AC		450		170	25			0.05	1.00	0.030	0.030	0.75	bal.	19.5	2.5	Cu 1.5 Fe 28.0 Nb 0.70
			650										1.20		23.5	3.5	Cu 3.0 Fe 32.0 Nb 1.00
C-NiSi9Cu3	heat to [970-1000C] AC							300	0.12	1.50	0.030	0.030	8.5	bal.			Cu 2.0
													10.0		1.0		Cu 4.0

<sup>A</sup> See original specification for full details

## Lloyd's Register Rule 2.4.8 STEEL CASTINGS PART 2, CHAPTER 4, SECTION 8: AUSTENITIC STAINLESS STEEL CASTINGS

This Section gives the requirements for castings in austenitic stainless steels for piping systems in ships for liquefied gases where the design temperature is not lower than -165 C, and in bulk chemical tankers.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests Impact	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
304L			430		215	26	40	[41 J @ -196 C]	0.03	0.50		0.040	0.20	8.0	17.0		
304			480		220	26	40	[41 J @ -196 C]	0.08	2.0	0.040	0.040	1.5	12.0	21.0		
316L			430		215	26	40	[41 J @ -196 C]	0.03	0.50	0.040	0.040	0.20	9.0	17.0	2.0	
316			480		240	26	40	[41 J @ -196 C]	0.08	2.0	0.040	0.040	1.5	13.0	21.0	3.0	
317									0.08	0.50	0.040	0.040	0.20	9.0	17.0	3.0	
347			480		215	22	35	[41 J @ -196 C]	0.08	2.0	0.040	0.040	1.5	12.0	21.0	4.0	
									0.06 <sub>C</sub>	2.0	0.040	0.040	0.20	9.0	17.0		Nb ≥ 8 x C ≤ 0.90 <sub>C</sub>

<sup>A</sup> All castings are to be solution treated at a temperature of not less than [1000 C] and cooled rapidly in air, oil, or water<sup>B</sup> See original specification for full details such as non-destructive examination and intercrystalline corrosion tests<sup>C</sup> When guaranteed impact values at low temperature are not required, the maximum carbon content may be 0.08% and the maximum niobium may be 1.00%

## MIL-C-24707/3 CASTINGS, FERROUS, CORROSION-RESISTANT, AUSTENITIC, CHROMIUM-NICKEL

This specification covers austenitic chromium-nickel alloy castings for corrosion-resistant and low magnetic permeability applications.

PREVIOUS SPECIFICATION	REPLACEMENT SPECIFICATION
MIL specification (class)	MIL-C-24707/3 ASTM specification (grade)
MIL-S-17509 (I)	A 744 (CF-8)
MIL-S-17509 (II)	A 744 (CF-8C)
MIL-S-17509 (III)	A 744 (CF-8M)
MIL-S-867 (I)	A 744 (CF-8)
MIL-S-867 (II)	A 744 (CF-8C)
MIL-S-867 (III)	A 744 (CF-8M)

Additional notes for specification are as follows; see original military specification booklet for further information, including Quality Assurance Provisions. Two different levels may be specified; level I has no magnetic restrictions and level II has low relative magnetic permeability. For all grades, supplementary requirements SZ1 (intergranular corrosion test) and SZ2 (tension test) of ASTM A 744 shall be mandatory. When type II is specified, the relative magnetic permeability of the castings shall not exceed 1.3 for first article and 1.6 for quality conformance tests; unless otherwise specified, the field strength shall be 0.5 oersteds for first article testing. Heat treat casting per ASTM A 744 except the minimum temperature shall be 1950 F. After all cleaning and machining, the casting shall be passivated in accordance with QQ-P-35.

MIL-C-24707/6

CASTINGS, FERROUS, CHROMIUM STEEL, FOR PRESSURE-CONTAINING PARTS SUITABLE FOR HIGH-TEMPERATURE SERVICE

This specification covers 12% chromium steel castings for high temperatures and for impact at low temperatures.

PREVIOUS SPECIFICATION	REPLACEMENT SPECIFICATION
MIL specification (class)	MIL-C-24707/6 ASTM specification (grade)
MIL-S-16993 (1)	A 217 (CA-15)
MIL-S-16993 (2)	A 487 (CA-15M, class A)

Additional notes for specification are as follows; see original military specification booklet for further information, including Quality Assurance Provisions. ASTM A 757 grade E3N castings are intended for use where either CA-15 or CA-15M is used; grade E3N has better weldability, corrosion and erosion resistance, low temperature properties such as notch toughness, and improved soundness and casting characteristics. CA-15M castings shall be normalized and tempered only with a tempering temperature not less than 1100 F; a liquid quench shall not be used without the permission of the Command or agency concerned.

# SUMMARY OF MATERIAL SPECIFICATIONS FOR CENTRIFUGALLY CAST STEELS

Below is a list of centrifugally cast steel specifications, with summary details on the following pages. Note that the values given in the summary of the specifications are stated with either U.S. Conventional Units (USCS) or Metric (SI) units, and are to be regarded separately. Units given in brackets are SI units. The values stated in each system are not exact equivalents (soft conversion); therefore, each system must be used independently of the other. Combining values from the two systems, by using conversion equations (hard conversion), may result in nonconformance with the specification. Also note that the values in the table are given in a minimum over maximum format. This means that if the value is a minimum it will be listed in the upper portion of the specification's table row and in the lower portion of the row if it is a maximum value. Finally, note that tables and their footnotes may be split across two or more pages.

ASTM A 426 – 92	Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service
ASTM A 451 – 93	Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service
ASTM A 452 – 88	Centrifugally Cast Austenitic Steel Cold-Wrought Pipe for High-Temperature Service
ASTM A 608 – 91a	Centrifugally Cast Iron-Chromium-Nickel High-Alloy Tubing for Pressure Application at High Temperatures
ASTM A 660 – 91a	Centrifugally Cast Carbon Steel Pipe for High Temperature Service
ASTM A 872 – 91	Centrifugally Cast Ferritic/Austenitic Stainless Steel Pipe for Corrosive Environments
ISO WD 13585(c)	Centrifugally cast tube

This specification covers centrifugally cast alloy steel pipe intended for use in high-temperature, high-pressure service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests <sub>B</sub> Hardness (HBN)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CP1 J12521	NT, QT 1100F [595C]	65	450	35	240	24	35	201	0.25	0.30	0.040	0.045	0.10			0.44	
CP2 J11547	NT, QT 1100F [595C]	60	415	30	205	22	35	201	0.10	0.30	0.040	0.045	0.10		0.50	0.44	
CP5 J42045	NT, QT 1250F [677C]	90	620	60	415	18	35	225	0.20	0.30	0.040	0.045	0.50		0.81	0.65	
CP5b J51545	NT, QT 1250F [677C]	60	415	30	205	22	35	225	0.15	0.30	0.040	0.045	1.00		4.00	0.45	
CP9 J82090	NT, QT 1250F [677C]	90	620	60	415	18	35	225	0.20	0.30	0.040	0.045	2.00		4.00	0.45	
CP11 J12072	NT, QT 1100F [595C]	70	485	40	275	20	35	201	0.05	0.30	0.040	0.045	0.25		6.00	0.65	
CP12 J11562	NT, QT 1100F [595C]	60	415	30	205	22	35	201	0.20	0.65	0.040	0.045	1.00		8.0	0.90	
CP15 J11522	NT, QT 1100F [595C]	60	415	30	205	22	35	201	0.05	0.30	0.040	0.045	1.00		10.0	1.20	
CP21 J31545	NT, QT 1250F [677C]	60	415	30	205	22	35	201	0.05	0.30	0.040	0.045	0.60		1.00	0.44	
CP22 J21890	NT, QT 1250F [677C]	60	415	30	205	22	35	201	0.20	0.80	0.040	0.045	0.60		1.50	0.65	
CPCA15 J91150/71	NT, QT 1250F [677C]	60	415	30	205	22	35	201	0.15	0.61	0.040	0.045	0.50		0.80	0.44	
		60	415	30	205	22	35	201	0.15	0.30	0.040	0.045	0.15		1.25	0.65	
		60	415	30	205	22	35	201	0.15	0.60	0.040	0.045	0.15			0.44	
		60	415	30	205	22	35	201	0.05	0.30	0.040	0.045	1.65			0.65	
		60	415	30	205	22	35	201	0.05	0.30	0.040	0.045	0.50		2.65	0.80	
		70	485	40	275	20	35	201	0.15	0.60	0.040	0.045	0.50		3.35	1.06	
		70	485	40	275	20	35	201	0.05	0.30	0.040	0.045	0.60		2.00	0.90	
		90	620	65	450	18	30	201	0.15	0.70	0.040	0.045	0.60		2.75	1.20	
		90	620	65	450	18	30	225	0.15	1.00	0.040	0.040	1.50		11.5	0.50	

<sub>A</sub> Minimum tempering temperature given

<sub>B</sub> Hydrostatic test – see original specification for further details

This specification covers austenitic alloy steel pipe for use in high-temperature, corrosive, or nuclear pressure service.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Hydrostatic Test <sub>C</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CPF3 J92500	ST 1900F [1040C]	70	485	30	205	35			0.03	1.50	0.040	0.040	2.00	8.0 12.0	17.0 21.0		
CPF3A <sub>A</sub> J92500	ST 1900F [1040C]	77	535	35	240	35			0.03	1.50	0.040	0.040	2.00	8.0 12.0	17.0 21.0		
CPF3M J92800	ST 1900F [1040C]	70	485	30	205	30			0.03	1.50	0.040	0.040	1.50	9.0 13.0	17.0 21.0	2.0 3.0	
CPF8 J92600	ST 1900F [1040C]	70	485	30	205	35			0.08	1.50	0.040	0.040	2.00	8.0 11.0	18.0 21.0		
CPF8A <sub>A</sub> J92600	ST 1900F [1040C]	77	535	35	240	35			0.08	1.50	0.040	0.040	2.00	8.0 11.0	18.0 21.0		
CPF8M J92900	ST 1900F [1040C]	70	485	30	205	30.0			0.08	1.50	0.040	0.040	1.50	9.0 12.0	18.0 21.0	2.0 3.0	

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade And UNS	Heat Treatment <sub>B</sub>	Tensile Strength		Yield Strength		Elong <sub>A</sub> %	Red A <sub>0</sub> %	Other Tests Hydrostatic Test <sub>C</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
CPF10MC	ST 1950F [1065C]	70	485	30	205	20.0			0.10	1.50	0.040	0.040	1.50	13.0	15.0	1.75	Cb 10 x C
CPH10	ST 2100F [1150C]	70	485	30	205	30.0								16.0	18.0	2.25	Cb 1.2 <sub>E</sub>
J93402									0.10	1.50	0.040	0.040	2.00	12.0	22.0		
CPF8C	ST 1950F [1065C]	70	485	30	205	30.0			0.10	1.50	0.040	0.040	2.00	15.0	26.0		
J92710									0.08	1.50	0.040	0.040	2.00	9.0	28.0		Cb 8 x C
CPF8C (Ta max) <sub>D</sub>	ST 1950F [1065C]	70	485	30	205	30.0			0.08	1.50	0.040	0.040	2.00	12.0	21.0		Cb 1 <sub>E</sub>
									0.08	1.50	0.040	0.040	2.00	9.0	18.0		Cb 8 x C
CPH8	ST 2100F [1150C]	65	448	28	195	30.0								12.0	22.0		Cb 1 Ta 0.10
J93400									0.08	1.50	0.040	0.040	1.5	15.0	26.0		
CPK20	ST 2100F [1150C]	65	448	28	195	30.0								19.0	23.0		
J94202									0.20	1.50	0.040	0.040	1.75	22.0	27.0		
CPH20	ST 2100F [1150C]	70	485	30	205	30.0								12.0	22.0		
J93402									0.20 <sub>F</sub>	1.50	0.040	0.040	2.00	15.0	26.0		
CPE 20N	ST 2225F [1218C]	80	550	40	275	30.0								8.0	23.0		N 0.08
									0.20	1.50	0.040	0.040	1.50	11.0	26.0		N 0.20

<sub>A</sub> The properties shown are obtained by adjusting the composition within the limits shown in the table to obtain a ferrite-austenite ratio that will result in the higher ultimate yield strengths indicated – a lowering of impact values may develop in these materials when exposed to service temperature above 800 F

<sub>B</sub> The pipe shall receive a solution treatment, ST, at the temperature shown with holding time 2 h/in of thickness [50.8 mm] for CPF10MC, CPF8C, and CPF8C (Ta max), and 1 h/in of thickness for all others, followed by quenching

<sub>C</sub> Hydrostatic test – see original specification for further details

<sub>D</sub> No designation as yet assigned by ASTM or SFSA

<sub>E</sub> Grades CPF10MC and CPF8C have a columbium plus tantalum content maximum of 1.35%

<sub>F</sub> By agreement between the manufacturer and the purchaser, the carbon content of Grade CPH20 may be restricted to 0.10% maximum – when so agreed, the grade designation shall be CPH10

## ASTM A 452 – 88

## CENTRIFUGALLY CAST AUSTENITIC STEEL COLD-WROUGHT PIPE FOR HIGH-TEMPERATURE SERVICE

This specification covers austenitic steel pipe made by the centrifugal casting process, subsequently cold worked, and given a recrystallizing anneal. Pipe ordered to this specification is suitable for use in high-pressure, high-temperatures services shall be suitable for bending and for other forming operations and for fusion welding. Selection will depend on design, service conditions, mechanical properties, and high-temperature characteristics.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong <sub>A</sub> %	Red A <sub>0</sub> %	Other Tests <sub>E</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
TP304H	ST 1800F [980C] <sub>A</sub>	75	517	30	207	45L <sub>B</sub>	50L <sub>B</sub>		0.04					8.00	18.0		
J92590									0.10	2.00	0.040	0.030	0.75	11.0	20.0		
						45T <sub>B</sub>	50T <sub>B</sub>										
						35L <sub>C</sub>	30L <sub>C</sub>										
						25T <sub>C</sub>	20T <sub>C</sub>										
TP347H	ST 2000F [1095C] <sub>A</sub>	75	517	30	207	45L <sub>B</sub>	50L <sub>B</sub>		0.04					9.00	17.0		Cb+Ta 8 x C
J92660									0.10	2.00	0.040	0.030	0.75	13.0	20.0		Cb+Ta <1.00
						45T <sub>B</sub>	50T <sub>B</sub>										
						35L <sub>C</sub>	30L <sub>C</sub>										

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong <sub>D</sub>	Red A <sub>0</sub>	Other Tests <sub>E</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
TP316H J92920	ST 1800F [980C] <sub>A</sub>	75	517	30	207	25T <sub>C</sub>	20T <sub>C</sub>										
						45L <sub>B</sub>	50L <sub>B</sub>		0.040					11.0	16.0		
						45T <sub>B</sub>	50T <sub>B</sub>		0.10	2.00	0.040	0.030	0.75	14.0	18.0		
						35L <sub>C</sub>	30L <sub>C</sub>										
						25T <sub>C</sub>	20T <sub>C</sub>										

<sub>A</sub> Subsequent to final cold working the pipe shall be heated to the temperature shown and then quenched

<sub>B</sub> For sizes 8 in [203 mm] nominal OD and greater

<sub>C</sub> For sizes less than 8 in [203 mm] nominal OD

<sub>D</sub> For elongation and reduction of area values L = longitudinal and T = transverse tests

<sub>E</sub> Additional tests required are: hydrostatic, flattening, magnetic permeability, and grain size

ASTM A 608 – 91a

CENTRIFUGALLY CAST IRON-CHROMIUM-NICKEL HIGH-ALLOY TUBING FOR PRESSURE APPLICATION AT HIGH TEMPERATURES

This specification covers iron-chromium-nickel, high-alloy tubes made by the centrifugal casting process intended for use under pressure at high temperatures.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests Pressure Test	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
HC 30	as cast								0.25	0.5			0.50		26		
J92613									0.35	1.0	0.04	0.04	2.00	4.0	30	0.50	
HD 50	as cast								0.45				0.50	4	26		
J92615									0.55	1.50	0.04	0.04	2.00	7	30	0.50	
HE 35	as cast								0.30				0.50	8	26		
J93413									0.40	1.50	0.04	0.04	2.00	11	30	0.50	
HF 30	as cast								0.25				0.50	9	19		
J92803									0.35	1.50	0.04	0.04	2.00	12	23	0.50	
HH 30	as cast								0.25				0.50	11	24		
J93513									0.35	1.50	0.04	0.04	2.00	14	28	0.50	
HH 33 <sub>A</sub>	as cast								0.28				0.50	12	24		
J93633									0.38	1.50	0.04	0.04	2.00	14	26	0.50	
HI 35	as cast								0.30				0.50	14	26		
J94613									0.40	1.50	0.04	0.04	2.00	18	30	0.50	
HK 30	as cast								0.25				0.50	19	23		
J94203									0.35	1.50	0.04	0.04	2.00	22	27	0.50	
HK 40	as cast								0.35				0.50	19	23		
J94204									0.45	1.50	0.04	0.04	2.00	22	27	0.50	
HL 30	as cast								0.25				0.50	18	28		
N08613									0.35	1.50	0.04	0.04	2.00	22	32	0.50	
HL 40	as cast								0.35				0.50	18	28		
N08614									0.45	1.50	0.04	0.04	2.00	22	32	0.50	
HN 40	as cast								0.35				0.50	23	19		
J94214									0.45	1.50	0.04	0.04	2.00	27	23	0.50	



ASTM A 608 Continued

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong	Red A	Other Tests Pressure Test	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
HT 50	as cast								0.40				0.50	33	15		
N08050									0.60	1.50	0.04	0.04	2.00	37	19	0.50	
HU 50	as cast								0.40				0.50	37	17		
N08005									0.60	1.50	0.04	0.04	2.00	41	21	0.50	
HW 50	as cast								0.40				0.50	58	10		
N08006									0.60	1.50	0.04	0.04	2.00	62	14	0.50	
HX 50	as cast								0.40				0.50	64	15		
N06050									0.60	1.50	0.04	0.04	2.00	68	19	0.50	

<sup>A</sup> Manufacturing control should ensure that this composition contain a minimal amount of ferrite

ASTM A 660 – 91a

CENTRIFUGALLY CAST CARBON STEEL PIPE FOR HIGH TEMPERATURE SERVICE

This specification covers carbon steel pipe made by the centrifugal casting process intended for use in high-temperature, high-pressure service. Pipe ordered under this specification shall be suitable for fusion welding, bending, and other forming operations.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment <sub>A</sub>	Tensile Strength		Yield Strength		Elong	Red A	Other Tests <sub>B</sub>	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa	%	%										
WCA		60	414	30	207	24	35		0.25 <sub>A</sub>	0.70 <sub>A</sub>	0.035	0.035	0.60				
J02504																	
WCB		70	483	36	248	22	35										
J03003									0.30	1.00	0.035	0.035	0.60				
WCC		70	483	40	276	22	35										
J02505									0.25 <sub>B</sub>	1.20 <sub>B</sub>	0.035	0.035	0.60				

<sup>A</sup> Heat treatment per design and chemical composition

<sup>B</sup> Hydrostatic and flattening tests – see original specification for further details

<sup>C</sup> For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% manganese above the specified maximum will be permitted to a maximum of 1.10%

<sup>D</sup> For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% manganese above the specified maximum will be permitted to a maximum of 1.40%

ASTM A 872 – 91

CENTRIFUGALLY CAST FERRITIC/AUSTENITIC STAINLESS STEEL PIPE FOR CORROSIVE ENVIRONMENTS

This specification covers centrifugally cast ferritic/austenitic steel pipe intended for general corrosive service. These steels are susceptible to embrittlement if used for prolonged periods at elevated temperatures.

GRADE & HEAT TREATMENT		MECHANICAL PROPERTIES (minimum unless range given)							CHEMICAL COMPOSITION, % (maximum percent unless range given)								
Grade and UNS	Heat Treatment	Tensile Strength		Yield Strength		Elong %	Red A %	Other Tests Hardness (HBN / HRC)	C	Mn	P	S	Si	Ni	Cr	Mo	Other
		ksi	MPa	ksi	MPa												
J93183	WQ 1900-2100F [1050-1150C]	90	620	65	420	25		290 / 30.5	0.030	2.0	0.040	0.030	2.0	4.00	20.0	2.00	N 0.08 Co 0.50
														6.00	23.0	4.00	N 0.25 Co 1.50 Cu 1.00
J93550	WQ 1900-2100F [1050-1150C]	90	620	65	420	20		297 / 31.5	0.030	2.0	0.040	0.030	2.0	5.00	23.0	2.00	N 0.08 Co 0.50
														8.00	26.0	4.00	N 0.25 Co 1.50 Cu 1.00

ISO WD 13585(c)

CENTRIFUGALLY CAST TUBE

See original specification for details.

# SUMMARY OF STANDARD TEST METHODS FOR STEEL CASTINGS

## Overview

Testing is required to ensure that the product will perform safely and economically in service. Excessive testing and overly stringent requirements increase the cost of the product without increasing value. On the other hand, insufficient testing or overly lax requirements are meaningless. Therefore, it becomes the task of the customer to decide what tests and requirements are necessary for his or her application.

Mechanical properties and chemical compositional limits are generally the subject of ASTM material specifications. These must be controlled and tested in products ordered to those specifications. Consult the latest revisions of the ASTM Standards referenced in this document for more information.

## Mechanical Testing

### **Background**

Mechanical testing is generally carried out in accordance with methods described in ASTM A 370, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products". These methods cover procedures and definitions for the mechanical testing of wrought and cast steel products. The various mechanical tests herein described are used to determine properties required in the product specifications. Variations in testing methods are to be avoided and standard methods of testing are to be followed to obtain reproducible and comparable results. The test methods most often used in steel castings include tension testing, hardness testing, and impact testing.

The mechanical properties are obtained from test bars and represent the quality of the steel from which the castings have been poured. The properties are not identical with the properties of the castings, which are affected by solidification rates and cooling rates during heat treating, which in turn are influenced by casting thickness, size, and shape.

### **Tension Testing**

The tension test is the most uniformly applied test used to verify the mechanical performance of the material. The test results include tensile strength, yield strength, elongation and reduction in area. The strength measurements are useful in determining the load bearing capabilities of the material. Ductility measurements give an indication of the ability of the material to undergo deformation. The tension test is used to verify that the mechanical performance of the material is consistent. Evaluating performance in service environments may require information of other material properties such as fracture toughness, fatigue, creep-rupture, etc.

### **Hardness Testing**

Hardness testing is used as a quick estimation of strength and/or wear resistance. It is particularly useful in the control of heat treatment for carbon and low to medium alloy steels. The most commonly used method for determining hardness in steel castings is the Brinell Test. The Rockwell test uses a much smaller probe and when used on cast steels is subject to variations. Converting numbers must be done with care because the conversions from Brinell to Rockwell is not exact and varies somewhat depending on the actual alloy tested. Stainless cast steels, excluding martensitic grades, are treated for corrosion resistance, not to develop strength and the hardness does not relate to heat treatment.

### **Impact Testing**

Impact testing gives the amount of energy absorbed by a material. A sample of the material is hit with a hammer that has a known energy. The difference in energy the hammer has after striking the material is the impact strength of the material. This provides a useful measure of toughness or resistance to sudden failure. For low temperature service this test becomes increasingly important because most steels become less tough as the

temperature decreases. Impact testing is an ASTM requirement in specifications for material used in low temperature service. The Charpy V-notch is the most commonly applied method.

## Nondestructive Examination

### Background

Nondestructive examination testing is done to verify the mechanical integrity or soundness of the steel casting. It can be separated into surface examination methods which include visual, liquid penetrant, and magnetic particle and subsurface or internal examination methods which include radiography and ultrasonics. Not only must a test method be chosen, but also an acceptance criterion must be applied. Acceptance criteria should be related to the service requirements because overly stringent criteria add directly to the cost. For critical service both surface and internal examination may be required to assure the attainment of the level of soundness specified.

### Visual Examination

Equipment Required	Enables Detection of	Advantages	Limitations	Remarks
Surface comparator  Pocket rule  Straight Edge  Workmanship standards	Surface flaws – cracks, porosity, slag inclusions, adhering sand, scale, etc.	Low cost  Can be applied while work is in process, permitting correction of faults	Applicable to surface defects only  Provides no permanent record	Should always be the primary method of inspection, no matter what other techniques are required

ASTM A 802/A 802M – 95      Standard Practice for Steel Castings, Surface Acceptance Standards, Visual Examination

SCRATA Comparators      Steel Casting Research and Trade Association (SCRATA) Comparator Plates - for establishing mutually agreeable acceptance criteria for a specific part

ISO DIS 1197(a)      Visual examination of surface quality of steel castings

MSS SP-55-1996      Quality Standard for Steel Castings for Valves, Flanges and Fittings, and Other Piping Components (Visual Method for Evaluation of Surface Irregularities)

### Liquid Penetrant Examination (PT)

Equipment Required	Enables Detection of	Advantages	Limitations	Remarks
Commercial kits, containing fluorescent or dye penetrants and developers  Application equipment for the developer  A source of ultraviolet light – if fluorescent method is used	Surface discontinuities not readily visible to the unaided eye	Applicable to magnetic, nonmagnetic materials  Easy to use  Low cost	Only surface discontinuities are detectable	

ASTM A 903/A 903M – 91      Steel Castings, Surface Acceptance Standards, Magnetic Particle and Liquid Penetrant Inspection

ASTM E 165 – 95      Standard Test Method for Liquid Penetrant Examination

ASTM E 433 – 71      Standard Reference Photographs for Liquid Penetrant Examination

ISO 3452      Non-destructive testing – Penetrant inspection – General principles

**Magnetic Particle Examination (MT)**

<b>Equipment Required</b>	<b>Enables Detection of</b>	<b>Advantages</b>	<b>Limitations</b>	<b>Remarks</b>
Special commercial equipment  Magnetic powders – dry or wet form; may be fluorescent for viewing under ultraviolet light	Excellent for detecting surface and subsurface discontinuities to approximately $\frac{1}{4}$ " below the surface – especially cracks	Permits controlled sensitivity  Relatively low cost method	Applicable to ferromagnetic materials only  Requires skill in interpretation of indications and recognition of irrelevant patterns  Difficult to use on rough surfaces	Elongated discontinuities parallel to the magnetic field may not give pattern; for this reason the filed should be applied from two directions at or near right angles to each other

ASTM A 903/A 903M – 91

Steel Castings, Surface Acceptance Standards, Magnetic Particle and Liquid Penetrant Inspection

ASTM E 709 – 95

Standard Guide for Magnetic Particle Examination

ASTM E 125 – 63

Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings

ASTM E 1444 – 94a

Standard Practice for Magnetic Particle Examination

ISO 4986

Steel castings – Magnetic particle inspection

MSS SP-53-1995

Quality Standard for Steel Castings and Forgings for Valves, Flanges and Fittings, and Other Piping Components (Magnetic Particle Examination Method)

All the surface examinations require severity levels to be set for acceptance. Methods of establishing severity levels by assigning numerical values to discontinuity attributes are illustrated in Figure 1 for the length of single linear discontinuities and arrays of aligned linear or nonlinear discontinuities. For nonlinear indications, acceptance criteria are typically expressed by limiting the “major” dimension of the indication, the length and width, or the area of the indication. Note, Figure 1 is an example and is not part of any acceptance standard unless agreed upon by the producer and buyer of steel castings.

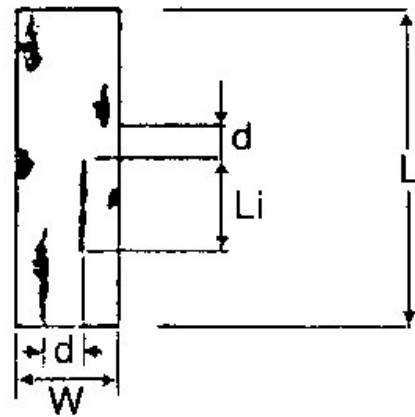
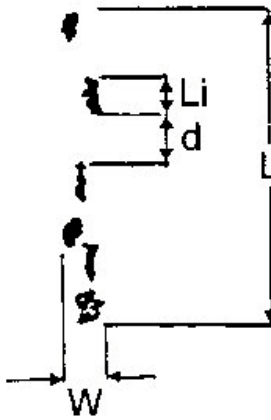
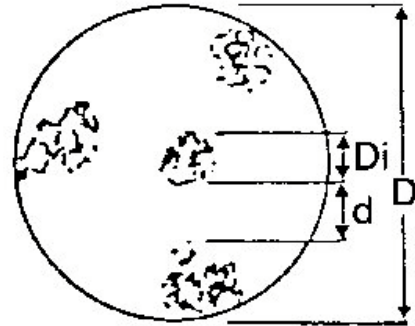
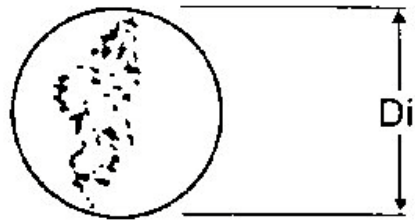


Figure 1: Length measurement of linear discontinuities; linear arrays of linear and non-linear discontinuities

Figure 2: Area measurement; diameter or length, and width measurement of discontinuity arrays

$L_i$ ,  $W_i$ ,  $D_i$  = Length, width, diameter of individual discontinuities, or clusters

$L$ ,  $W$ ,  $D$  = Length, width, diameter of discontinuity arrays

$d$  = Distance between discontinuities, or discontinuity clusters

Linear discontinuity =  $L_i \geq 3W_i$

Linear array =  $L \geq 5W$

Distance between discontinuities within an array =  $d < L_{i_{max}}$ , that is,  $d < D_{i_{max}}$

$L_{i_{max}}$ ,  $D_{i_{max}}$  = Largest length, or diameter of discontinuity, or cluster within an array

The ASME Code has methods and acceptance criteria in Section III and Section VIII. In Section VIII (non-nuclear) para. 9-103(a) and 9-230(a) no linear discontinuities are allowed. This is a classic example of overly strict requirements because it requires all discontinuities to be eliminated. In Section III (nuclear) para. NB-2545.3 and NB-2546.3 allow indications of 1/16". The nuclear section is actually easier to comply with because it does allow for some small indications without rework. The code contains high standards of quality, but these need not be used for all castings for all applications. Rather, the service conditions should be used to help choose appropriate levels of acceptance.

## Radiographic Examination (RT)

Equipment Required	Enables Detection of	Advantages	Limitations	Remarks
Commercial x-ray or gamma units, made especially for inspecting welds, castings, and forgings  Film and processing facilities	Internal macroscopic flaws – cracks, porosity, blow holes, non-metallic inclusions, shrinkage, etc.	When the indications are recorded on film, gives a permanent record	Requires skill in choosing angles of exposure, operating equipment, and interpreting indications  Requires safety precautions  Cracks difficult to detect	Radiographic inspection is required by many codes and specifications  Useful in qualification of processes  Because of cost, its use should be limited to those areas where other methods will not provide the assurance required

ASTM E 94 – 93	Standard Guide for Radiographic Testing
ASTM E 142 – 92	Standard Method for Controlling Quality of Radiographic Testing
ASTM E 446 – 93	Standard Reference Radiographs for Steel Castings up to 2 in. in Thickness (3 Sets; X-rays, Iridium, Cobalt)
ASTM E 186 – 93	Standard Reference Radiographs for Heavy-walled (2 to 4-1/2 in.) Steel Castings (3 Sets; X-ray, Gamma Rays, Betatron)
ASTM E 280 – 93	Standard Reference Radiographs for Heavy-walled (4-1/2 to 12 in.) Steel Castings (2 Sets; X-ray, Betatron)
ASTM E192 – 95	Standard Radiographs of Investment Steel Castings for Aerospace Applications
ISO 4993	Steel castings – Radiographic inspection
ISO 5579	Non-destructive testing – Radiographic examination of metallic materials by X- and gamma rays – Basic rules
MSS SP-54-1995	Quality Standard for Steel Castings for Valves, Flanges and Fittings, and Other Piping Components (Radiographic Examination Method)

## Ultrasonic Testing (UT)

Equipment Required	Enables Detection of	Advantages	Limitations	Remarks
Special commercial equipment, either of the pulse-echo or transmission type	Sub-surface discontinuities, including those too small to be detected by other methods  Especially for detecting subsurface, planar discontinuities	Very sensitive  Permits probing of joints inaccessible to radiography	Requires high degree of skill in interpreting pulse-echo patterns  Permanent record is not readily obtained	

ASTM A 609/A 609M - 91	Standard Practice for Castings, Carbon, Low-alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof
ISO DIS 4992(a)	Steel castings – Ultrasonic inspection
MSS SP-94-1992	Quality Standard for Ferritic and Martensitic Steel Castings for Valves, Flanges and Fittings, and Other Piping Components (Ultrasonic Examination Method)

# SPECIAL STANDARD PRACTICES

## Ferrite Content

ASTM A 800/A 800M

### STEEL CASTINGS, AUSTENITIC ALLOY, ESTIMATING FERRITE CONTENT THEREOF

This practice covers procedures and definitions for estimating ferrite content in certain grades of austenitic iron-chromium-nickel alloy castings that have compositions balanced to create the formation of ferrite as a second phase in amounts controlled to be within specified limits. Methods are described for estimating ferrite content by chemicals, magnetic, and metallographic means.

The tensile and impact properties, the weldability, and the corrosion resistance of iron-chromium-nickel alloy castings may be influenced beneficially or detrimentally by the ratio of the amount of ferrite to the amount of austenite in the microstructure. The ferrite content may be limited by purchase order requirements or by the design construction codes governing the equipment in which the castings will be used. The quantity of ferrite in the structure is fundamentally a function of the chemical composition of the alloy and its thermal history. Because of segregation, the chemical composition, and, therefore, the ferrite content, may differ from point to point on a casting. Determination of the ferrite content by any of the procedures described in the following practice ASTM A 800/A 800M is subject to varying degrees of imprecision which must be recognized in setting realistic limits on the range of ferritic content specified. Sources of error include the following:

1. In Determinations from Chemical Composition – Deviations from the actual quantity of each element present because of chemical analysis variance, although possibly minor in each case, can result in substantial differences in the ratio of total ferrite-promoting to total austenite-promoting elements. Therefore, the precision of the ferrite content estimated from chemical composition depends on the accuracy of the chemical analysis procedure.
2. In Determinations from Magnetic Response – Phases other than ferrite and austenite may be formed at certain temperatures and persist at room temperature. These may so alter the magnetic response of the alloy that the indicated ferrite content is quite different from that of the same chemical composition that has undergone different thermal treatment. Also, because the magnets or probes of the various measuring instruments are small, different degrees of surface roughness or surface curvature will vary the magnetic linkage with the material being measured.
3. In Determinations from Metallographic Examinations – Metallographic point count estimates of ferrite percentage may vary with the etching technique used for identification of the ferrite phase and with the number of grid points chosen for the examination, as explained in Test Method E 562.

ISO WD 13520(c)

### ESTIMATION OF FERRITE CONTENT IN AUSTENITIC STAINLESS STEEL CASTINGS

See original specification for details.

## Welding

ASTM A 488/A 488M

STEEL CASTINGS, WELDING, QUALIFICATIONS OF PROCEDURES AND PERSONNEL

This practice established the qualifications of procedures, welders, and operators for the fabrication and repair of steel castings by electric arc welding.

ISO WD 11970(c)

WELD QUALIFICATION PROCEDURES FOR STEEL CASTINGS



# CODE AND SPECIFICATION AGENCIES

## **American Society for Testing and Materials (ASTM)**

100 Barr Harbor Drive  
West Conshohocken, PA 19428  
(610) 832-9500  
[www.astm.org]

## **American National Standards Institute**

**(ANSI)** - US International Standards Organization (ISO) member  
11 W 42<sup>nd</sup> Street, 13<sup>th</sup> floor  
New York, NY 10036  
(212) 642-4900  
[www.ansi.org]

## **American Society of Mechanical Engineers**

**(ASME)** - Boiler and Pressure Vessel Code Committee  
PO Box 2900  
Fairfield, NJ 07007  
(800) 843-2763  
[www.asme.org]

## **American Petroleum Institute (API)**

275 7<sup>th</sup> Avenue, floor 9  
New York, NY 10001  
(212) 366-4040  
[www.api.org]

## **Manufacturers Standardization Society of the Valve and Fitting Industry, Inc. (MSS)**

127 Park Street NE  
Vienna, VA 22180-4602  
(703) 281-6613  
[www.mss-hq.com]

## **Society of Automotive Engineers (SAE)**

400 Commonwealth Drive  
Warrendale, PA 15096-0001  
(724) 776-4841  
[www.sae.org]

## **American Bureau of Shipping (ABS)**

2 World Trade Center, floor 106  
New York, NY 10048  
(212) 839-5000  
[www.eagle.org]

## **Lloyd's Register of Shipping (LR)**

20325 Center Ridge Road, Suite 670  
Cleveland, OH 44116  
(440) 331-3626  
[www.lr.org]

## **National Association of Corrosion Engineers (NACE)**

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Houston, TX 77084  
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