Age-hardened Nickel-based Alloys for Oil and Gas Drilling and Production Equipment

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Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the specification.

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Affected Publication: API Standard 6ACRA, *Age-hardened Nickel-based Alloys for Oil and Gas Drilling and Production Equipment*, First Edition, August 2015

Addendum 3

Section 1.1 shall be replaced with the following:

1.1 Purpose

This document provides requirements for age-hardened nickel-base alloys that are intended to supplement the existing requirements of API 6A. For downhole applications, refer to API 5CRA.

These additional requirements include detailed process control requirements and detailed testing requirements. The purpose of these additional requirements is to ensure that the age-hardened nickel-base alloys used in the manufacture of API 6A pressure-containing and pressure-controlling components are not embrittled by the presence of an excessive level of deleterious phases and meet the minimum metallurgical quality requirements.

NOTE Failures attributed to hydrogen-induced stress cracking (HISC) have been reported in production equipment and early in the life of subsea equipment made from age-hardened nickel-base alloys. Some age-hardened nickel-base alloys that meet the requirements of NACE MR0175 and API 6ACRA may be susceptible to HISC. Sources of hydrogen charging include but are not limited to galvanic coupling to a more active material, direct exposure to seawater with cathodic protection (CP), and decomposition of brines. The industry is evaluating alternate test methods and/or acceptance criteria to identify material with susceptibility to HISC.

In the table of contents, the entries for figures A.10 through A.17 shall be amended to the following:

Table 1: Replace Table 1 with the following:

Table 1—Chemical Composition [c,d]

	UNS Number							
Element	**N07716**	**N07718**	**N07725**	**N09925**	**N09935**	**N09945**	**N09946**	**N09955**
Ni	59.0 to 63.0	50.0 to 55.0	55.0 to 59.0	42.0 to 46.0	35.0 to 38.0	46.5 to 48.0	52.0 to 55.0	55.0 to 60.0
Cr	19.0 to 22.0	17.0 to 21.0	19.0 to 22.5	19.5 to 22.5	19.5 to 22.0	19.5 to 23.0	19.5 to 22.5	20.0 to 24.0
Fe[a]	Balance	Balance	Balance	22 min	Balance	Balance	Balance	Balance
Nb	2.75 to 4.00	—	2.75 to 4.00	0.08 to 0.50	0.20 to 1.00	2.80 to 3.50	3.80 to 4.50	4.0 to 5.5
Cb(Nb) + Ta	—	4.87 to 5.20	—	—	—	—	—	—
Mo	7.00 to 9.50	2.80 to 3.30	7.00 to 9.50	2.50 to 3.50	3.00 to 5.00	3.00 to 4.00	3.00 to 4.00	5.5 to 7.0
Ti	1.00 to 1.60	0.80 to 1.15	1.00 to 1.70	1.90 to 2.40	1.80 to 2.50	0.50 to 2.50	0.50 to 2.50	0.50 to 1.00
Al	0.35 max	0.40 to 0.60	0.35 max	0.10 to 0.50	0.50 max	0.01 to 0.70	0.01 to 0.70	0.25 to 0.80
C	0.030 max	0.045 max	0.030 max	0.025 max	0.030 max	0.005 to 0.040	0.005 to 0.030	0.030 max
Co	—	1.00 max	—	—	1.00 max	—	—	1.00 max
Mn	0.20 max	0.35 max	0.35 max	1.00 max	1.00 max	1.00 max	1.00 max	0.50 max
Si	0.20 max	0.35 max	0.20 max	0.35 max	0.35 max	0.50 max	0.50 max	0.50 max
P	0.015 max	0.010 max	0.015 max	0.020 max	0.025 max	0.020 max	0.020 max	0.015 max
S	0.010 max	0.010 max	0.010 max	0.003 max	0.001 max	0.010 max	0.010 max	0.0010 max
B	0.006 max	0.0060 max	—	—	—	—	—	0.0060 max
Cu	0.23 max	0.23 max	—	1.50 to 3.00	1.00 to 2.00	1.50 to 3.00	1.50 to 3.00	0.044 max
Pb	0.001 max	0.0010 max	—	—	—	—	—	—
Se	—	0.0005 max	—	—	—	—	—	—
Bi	—	0.00005 max	—	—	—	—	—	—
Ca[b]	—	0.0030 max	—	—	—	—	—	—
Mg[b]	—	0.0060 max	—	—	—	—	—	—
W	—	—	—	—	1.00 max	—	—	—

[a] Shall be determined arithmetically by difference or by direct measurement.

[b] To be determined if intentionally added.

[c] Some limits are more restrictive than the UNS chemistry.

[d] "—" Value not required

Section 4.1.2.1.3: Replace the section header with the following:

4.1.2.1.3 UNS N09925, UNS N09935, UNS N09945, UNS N09946, and UNS N09955

Table 2: The table shall be updated as indicated by the red boxes:

Table 2—Heat Treatment Procedures

UNS	Material Designation	Solution Annealing		Age Hardening
		Material Temperature	Time (hours)	Material Temperature and Time
N07716	120K 140K	1875 °F–1925 °F (1024 °C–1052 °C)	0.5 to 4 [b]	1310 °F–1455 °F (710 °C–791 °C) for 4–9 hours, furnace cool to 1125 °F–1275 °F (607 °C–691 °C), and hold for total aging time of 12 hours minimum [b]
N07718	120K	1870 °F–1925 °F (1021 °C–1052° C)	1 to 2.5 [a]	1425 °F–1475 °F (774 °C–802 °C) for 6–8 hours [b]
	140K	1870 °F–1925 °F (1021 °C–1052 °C)	1 to 2.5 [a]	1400 °F–1475 °F (760 °C–802 °C) for 6–8 hours [b]
	150K	1870 °F–1925 °F (1021 °C–1052 °C)	1 to 2.5 [c]	1292 °F–1382 °F (700 °C–750 °C) for 8 hours minimum, furnace cool to 1112 °F–1202 °F (600 °C–650 °C), and hold for 8 hours minimum [d]
N07725	120K	1875 °F–1950 °F (1024 °C–1066 °C)	0.5 to 4 [b]	1325 °F–1425 °F (718 °C–774 °C) for 4–9 hours, furnace cool to 1125 °F–1275 °F (607 °C–691 °C), and hold for total aging time of 12 hours minimum [b]
N09925	110K	1825 °F–1925 °F (996 °C–1052 °C)	0.5 to 4 [a]	1325 °F–1400 °F (718 °C–760 °C) for 4–9 hours, furnace cool to 1125 °F–1220 °F (607 °C–660 °C), and hold for total aging time of 12 hours minimum [b]
N09935	110K	1870 °F–1975 °F (1021 °C– 1079 °C)	0.5 to 4 [a]	1345 °F–1435 °F (729 °C–779 °C) for 4–9 hours, furnace cool to 1165 °F–1255 °F (629 °C– 679 °C), and hold for total aging time of 12 hours minimum [b]
N09945	125K	1800 °F–1950°F (982 °C–1066°C)	0.5 to 4 [a]	1250 °F–1350 °F (677 °C–732 °C) for 4–9 hours, furnace cool to 1110 °F–1190 °F (599 °C–643 °C), and hold for total aging time of 12 hours minimum [b]
N09955	120K	1868 °F–1976 °F (1020 °C–1080 °C)	0.5 to 6 [a]	1328 °F–1436 °F (720 °C–780 °C) for 4–8 hours [d]
N09955	140K	1868 °F–1976 °F (1020 °C–1080 °C)	0.5 to 6 [a]	1328 °F–1436 °F (720 °C–780 °C) for 4–8 hours, air cooling to room temperature, heating at 1112 °F to 1202 °F (600 °C–650 °C) and hold for a combined total aging time for both cycles of 10 hours minimum [d]
N09946	140K	1800 °F–1950 °F (982 °C–1066 °C)	0.5 to 4 [a]	1250 °F–1350 °F (677 °C–732 °C) for 4–9 hours, furnace cool to 1110 °F–1190 °F (599 °C–643 °C), and hold for total aging time of 12 hours minimum [b]
N09946	150K	1800 °F–1925 °F (982 °C–1052 °C)	0.5 to 4 [a]	1250 °F–1350 °F (677 °C–732 °C) for 4–9 hours, furnace cool to 1110 °F–1190 °F (599 °C–643 °C), and hold for total aging time of 12 hours minimum [b]
N09946	160K	1825 °F–1950 °F (996 °C–1066 °C)	0.5 to 4 [a]	1250 °F–1350 °F (677 °C–732 °C) for 4–9 hours, furnace cool to 1110 °F–1190 °F (599 °C–643 °C), and hold for total aging time of 12 hours minimum [b]

[a] Cool in air, inert gas, water, polymer, or oil to ambient temperature. Air cooling or inert gas cooling of section thickness greater than 3 inches shall only be upon agreement between purchaser, manufacturer, and end user.

[b] Cool in air, inert gas, water, polymer, or oil to ambient temperature.

[c] Air cool or faster.

[d] Air cool.

Table 5: The table shall be updated as indicated by the red boxes:

Table 5—Tensile Requirements

UNS number	Material Designation	QTC Cross-section Thickness * in. (mm)	0.2% Yield Strength Min. ksi (MPa)	0.2% Yield Strength Max. ksi (MPa)	Tensile Strength Min. ksi (MPa)	Elongation in 4D Min. %	Reduction of Area Min. %
N07716	120K	≤10 (254)	120 (827)	150 (1034)	150 (1034)	20	35
		>10 (254)	120 (827)	150 (1034)	150 (1034)	20	25
	140K	≤10 (254)	140 (965)	160 (1103)	165 (1138)	18	30
		>10 (254)	140 (965)	160 (1103)	165 (1138)	18	20
N07718	120K	≤10 (254)	120 (827)	145 (1000)	150 (1034)	20	35
		>10 (254)	120 (827)	145 (1000)	150 (1034)	20	25
	140K	≤10 (254)	140 (965)	150 (1034)	165 (1138)	20	35
		>10 (254)	140 (965)	150 (1034)	165 (1138)	20	25
	150K	≤10 (254)	150 (1034)	175 (1207)	175 (1207)	20	35
		>10 (254)	150 (1034)	175 (1207)	175 (1207)	20	25
N07725	120K	≤10 (254)	120 (827)	150 (1034)	150 (1034)	20	35
		>10 (254)	120 (827)	150 (1034)	150 (1034)	20	25
N09925	110K	≤10 (254)	110 (758)	140 (965)	140 (965)	18	25
		>10 (254)	110 (758)	140 (965)	140 (965)	18	20
N09935	110K	≤10 (254)	110 (758)	140 (965)	140 (965)	18	25
		>10 (254)	110 (758)	140 (965)	140 (965)	18	20
N09945	125K	≤10 (254)	125 (862)	155 (1069)	150 (1034)	18	25
		>10 (254)	125 (862)	155 (1069)	150 (1034)	18	20
N09955	120K	≤10 (254)	120 (827)	145 (1000)	150 (1034)	25	45
		>10 (254)	120 (827)	145 (1000)	150 (1034)	25	40
	140K	≤10 (254)	140 (965)	155 (1069)	165 (1138)	20	40
		>10 (254)	140 (965)	155 (1069)	165 (1138)	20	35
N09946	140K	≤10 (254)	140 (965)	165 (1138)	165 (1138)	18	25
		>10 (254)	140 (965)	165 (1138)	165 (1138)	18	20
	150K	≤10 (254)	150 (1034)	170 (1172)	170 (1172)	18	25
		>10 (254)	150 (1034)	170 (1172)	170 (1172)	18	20
	160K	≤10 (254)	160 (1103)	180 (1241)	180 (1241)	18	25
		>10 (254)	160 (1103)	180 (1241)	180 (1241)	18	20

* QTC cross-section thickness at time of heat treatment

Table 6: The table shall be updated as indicated by the red boxes:

Table 6—Charpy V-notch Impact Toughness Requirements (10 mm x 10 mm)

UNS Number	Material Designation	QTC Cross-section [a] Thickness in. (mm)	Orientation [b]	Minimum Average ft-lbs (J)	Minimum Single ft-lbs (J)	Minimum Lateral Expansion in. (mm)
N07716	120K	< 3 (76)	Longitudinal	40 (54)	35 (47)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	37 (50)	32 (43)	0.015 (0.38)
		>10 (254)	Transverse	32 (43)	27 (37)	0.015 (0.38)
	140K	< 3 (76)	Longitudinal	40 (54)	35 (47)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
N07718	120K	< 3 (76)	Longitudinal	50 (68)	45 (61)	0.015 (0.38)
		≥3 (76) through 10 (254)	Transverse	35 (47)	30 (41)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
	140K	< 3 (76)	Longitudinal	50 (68)	45 (61)	0.015 (0.38)
		≥3 (76) through 10 (254)	Transverse	35 (47)	30 (41)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
	150K	< 3 (76)	Longitudinal	50 (68)	45 (61)	0.015 (0.38)
		≥3 (76) through 10 (254)	Transverse	35 (47)	30 (41)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
N07725	120K	< 3 (76)	Longitudinal	40 (54)	35 (47)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	37 (50)	32 (43)	0.015 (0.38)
		> 10 (254)	Transverse	32 (43)	27 (37)	0.015 (0.38)
N09925	110K	< 3 (76)	Longitudinal	35 (47)	32 (43)	0.015 (0.38)
		≥3 (76) through 10 (254)	Transverse	35 (47)	32 (43)	0.015 (0.38)
		> 10 (254)	Transverse	35 (47)	32 (43)	0.015 (0.38)
N09935	110K	< 3 (76)	Longitudinal	35 (47)	30 (41)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	30 (41)	25 (34)	0.015 (0.38)
		> 10 (254)	Transverse	25 (34)	20 (27)	0.015 (0.38)
N09945	125K	< 3 (76)	Longitudinal	50 (68)	45 (61)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	40 (54)	35 (47)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
N09946	140K	< 3 (76)	Longitudinal	45 (61)	40 (54)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	35 (47)	30 (41)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
	150K	< 3 (76)	Longitudinal	45 (61)	40 (54)	0.015 (0.38)
		≥ 3 (76) through 10 (254)	Transverse	35 (47)	30 (41)	0.015 (0.38)
		> 10 (254)	Transverse	30 (41)	27 (37)	0.015 (0.38)
	160K	≥ 3 (76) through 10 (254)	Transverse	27 (37)	25 (34)	0.015 (0.38)
		> 10 (254)	Transverse	27 (37)	25 (34)	0.015 (0.38)
N09955	120K	< 3 (76)	Longitudinal	70 (95)	65 (88)	0.025 (0.64)
		≥ 3 (76) through 10 (254)	Transverse	50 (68)	45 (61)	0.025 (0.64)
		> 10 (254)	Transverse	45 (61)	40 (54)	0.020 (0.51)
	140K	< 3 (76)	Longitudinal	60 (81)	55 (75)	0.020 (0.51)
		≥ 3 (76) through 10 (254)	Transverse	40 (54)	35 (47)	0.015 (0.38)
		> 10 (254)	Transverse	35 (47)	30 (41)	0.015 (0.38)

[a] QTC cross-section thickness at time of heat treatment.

[b] See 4.2.4.1 for specific requirements regarding the orientation.

Table 7: The table shall be updated as indicated by the red boxes:

Table 7—Hardness Requirements

UNS number	Material Designation	Minimum Hardness HRC (HBW)	Maximum Hardness HRC (HBW)
N07716	120K	32 ([a])	43 ([a])[c]
	140K	34 ([a])	43 ([a])[c]
N07718	120K	32 ([a])	40 ([a])[b]
	140K	34 ([a])	40 ([a])[b]
	150K	35 ([a])	45 ([a])[b]
N07725	120K	32 ([a])	43 ([a])[c]
N09925	110K	26 ([a])	38 ([a])[b]
N09935	110K	24 ([a])	34 ([a])[b]
N09945	125K	32 ([a])	42 ([a])[b]
N09946	140K	34 ([a])	42 ([a])[b]
	150K	35 ([a])	46 ([a])[c]
	160K	36 ([a])	46 ([a])[c]
N09955	120K	32 ([a])	40 ([a])[b]
	140K	34 ([a])	42 ([a])[b]

[a] The conversion of hardness readings to or from other scales is material-dependent. The Rockwell C scale is the preferred hardness method for hardness testing the family of alloys covered by API 6ACRA since compliance with ANSI/NACE MR0175 is frequently required and ANSI/NACE MR0175 specifies the maximum acceptable hardness limits using the Rockwell C scale. When conversions from other hardness scales to the Rockwell C scale are required or vice versa, one of two methods shall be used:

— a hardness conversion agreed to by the equipment manufacturer and the end user;
— ASTM E140 conversion.

When a conflict exists between Rockwell C scale hardness numbers and Brinell hardness numbers, the Rockwell C scale shall be the referee method.
When a conversion other than the ASTM E140 conversion is utilized, the conversion method shall be documented and traceable to test results.
In accordance with ASTM E140, when reporting converted hardness numbers, the measured hardness and test scale shall be reported in parentheses. For example, 20.0 HRC (228 HBW), where 20.0 HRC is the converted hardness value and 228 HBW is the original measurement value and test scale.

[b] Maximum hardness limits shall be in accordance with ANSI/NACE MR0175.

[c] These values represent the least-restrictive hardness limits presented in ANSI/NACE MR0175 for the individual alloys.
See ANSI/NACE MR0175 for hardness limits for specific temperature and/or elemental sulfur environments.

The captions for Figures A.10 through A.17 shall be replaced by the following:

Figure A.10—Acceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725

Figure A.11—Acceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Showing Isolated Grain Boundary Precipitation

Figure A.12—Acceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Showing Partial Coverage of Grain Boundaries with Second Phase Particles

Figure A.13—Acceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Showing Partial Coverage of Grain Boundaries with Second Phase Particles

Figure A.14—Unacceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Showing Full Coverage of Grain Boundaries with Second Phase Particles

Figure A.15—Unacceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Showing Acicular Grain Boundary Precipitates

Figure A.16—Unacceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Due To Acicular Precipitates

Figure A.17—Unacceptable Microstructure for UNS N09925, UNS N09935, UNS N09945, UNS N09946, UNS N09955, UNS N07716, and UNS N07725 Showing Grain Boundary Precipitates

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Introduction

This standard for Age-Hardened Nickel-Based Alloys was formulated by the API Committee on Standardization of Oilfield Equipment and Materials (CSOEM), Subcommittee on Valves and Wellhead Equipment (SC6), Materials Task Group. It is based on the conclusions of a task group evaluation of requirements needed for Age-Hardened Nickel-Based Alloys to supplement the existing requirements of API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*.

Age-hardened Nickel-based Alloys for Oil and Gas Drilling and Production Equipment

1 Scope

1.1 Purpose

This document provides requirements for age-hardened nickel-base alloys that are intended to supplement the existing requirements of API 6A. For downhole applications, refer to API 5CRA.

These additional requirements include detailed process control requirements and detailed testing requirements. The purpose of these additional requirements is to ensure that the age-hardened nickel-base alloys used in the manufacture of API 6A pressure-containing and pressure-controlling components are not embrittled by the presence of an excessive level of deleterious phases and meet the minimum metallurgical quality requirements.

NOTE Failures attributed to hydrogen-induced stress cracking (HISC) have been reported in production equipment and early in the life of subsea equipment made from age-hardened nickel-base alloys. Some age-hardened nickel-base alloys that meet the requirements of NACE MR0175 and API 6ACRA may be susceptible to HISC. Sources of hydrogen charging include but are not limited to galvanic coupling to a more active material, direct exposure to seawater with cathodic protection (CP), and decomposition of brines. The industry is evaluating alternate test methods and/or acceptance criteria to identify material with susceptibility to HISC.

1.2 Applicability

This standard is intended to apply to pressure-containing and pressure-controlling components as defined in API 6A. Requirements of this standard may be applied by voluntary conformance by a manufacturer, normative reference in API 6A or other product specification(s), or by contractual agreement.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*

ASTM A370 [1], *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A604, *Standard Practice for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets*

ASTM B880, *Standard Specification for General Requirements for Chemical Check Analysis Limits for Nickel, Nickel Alloys and Cobalt Alloys*

ASTM E10, *Standard Test Method for Brinell Hardness Test of Metallic Materials*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

ASTM E29*, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E110*, Standard Test Method for Rockwell and Brinell Hardness of Metallic Materials by Portable Hardness Testers*

[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959. www.astm.org