

Age-Hardened Nickel-Based Alloys for Oil and Gas Drilling and Production Equipment

API STANDARD 6A718
THIRD EDITION, DATE

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Upstream Segment

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FOREWORD

This Standard for **Age-Hardened Nickel-Based Alloys** was formulated by the API Exploration and Production Subcommittee on Valves and Wellheads (Committee 1, Subcommittee 6) 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 Spec 6A ~~and ISO 10423~~.

This standard shall become effective on the date printed on the cover, but may be used voluntarily from the date of distribution.

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Suggested revisions are invited and should be submitted to API, Standards department, 1220 L Street, NW, Washington, DC 20005.

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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-Based Alloys** that are intended to supplement the existing requirements of API Spec 6A ~~and ISO 10423~~. **For downhole applications refer to API5CRA.**

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-Based Alloys** used in the manufacture of API Spec 6A ~~or ISO 10423~~ 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.**

1.2 APPLICABILITY

This standard is intended to apply to pressure containing and pressure controlling components covered by API Spec 6A ~~and ISO 10423~~, but is not invoked by API Spec 6A ~~and ISO 10423~~. This standard is applicable when invoked by the equipment manufacturer or the equipment purchaser.

2 Normative References

The following normative documents contain provisions that, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document applies. Members of ISO and IEC maintain registers of currently valid standards.

API

Spec 6A *Specification for Wellhead and Christmas Tree Equipment*

ASTM ¹

A370 *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

A604 *Standard Test Method for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets*

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

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

E18 *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*

E112 *Standard Test Methods for Determining Average Grain Size*

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

- E354 *Test Methods for Chemical Analysis of High-Temperature Electrical, Magnetic, and Other Similar Iron, Nickel and Cobalt Alloys*
- E1019 *Standard test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel and Cobalt Alloys by Various Combustion and Fusion Techniques*
- E 1086 *Standard Test Method for Optical Emission Vacuum Spectrometric Analysis of Stainless Steel by Point-to-Plane Excitation Technique*
- E1181 *Standard Test Methods for Characterizing Duplex Grain Sizes*
- E1473 *Standard Test Methods for Chemical Analysis of Nickel, Cobalt, and High-Temperature Alloys*
- E2465 *Standard Test Method for Analysis of Nickel-Base Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry*

ISO²

~~10423 Petroleum and natural gas industries—Drilling and production equipment—Wellhead and christmas tree equipment~~

SAE³

AMS 2750 Pyrometry

3 Terms, Definitions and Abbreviated Terms

3.1 TERMS AND DEFINITIONS

For the purposes of this standard, the following terms and definitions apply:

3.1.1 deleterious phases: Secondary phases present in the microstructure of an alloy that have a negative effect on the desired mechanical properties, toughness, or corrosion resistance of the alloy.

3.1.2 delta phase: A secondary phase ~~which may be present~~ in ~~alloys containing Nb(Cb) Nickel-Base Alloy 718~~. Delta phase can be globular or acicular, has an orthorhombic crystal structure, and has a chemical composition described as Ni₃Nb type.

3.1.3 total hot work reduction ratio: The total hot work reduction ratio is defined as the product of the individual reduction ratios achieved at each step in the hot work operation from ingot cross section to final hot work cross section, where the ingot cross section shall be the cross section of the ingot obtained after the last remelt step and any ingot grinding or surface preparation prior to hot working.

3.1.3 Heat Treat Lot : Material from the same remelt ingot, processed together using the same procedures and hot/cold work equipment, same nominal dimensions (excluding length) and heat treated in the same furnace loads, including solution annealing, aging and, if applicable, re-heat treatment

3.2 ABBREVIATED TERMS

For the purpose of this standard, the following abbreviated terms apply:

² International Organization for Standardization, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. www.iso.org

³ SAE International, 400 Commonwealth Dr, Warrendale, PA 15096-001, USA, www.sae.org

AOD	Argon Oxygen Decarburization
EF	Electric Furnace or Electric Arc Furnace (EAF)
EFR	Electroflux Remelting (same as ESR)
ER	Equivalent Round
ESR	Electro-slag Remelting
QTC	Qualification Test Coupon
VAR	Vacuum Arc Remelting
VIM	Vacuum Induction Melting
VOD	Vacuum Oxygen Decarburization

4. Requirements for **Age-Hardened Nickel-Based Alloys-718 (UNS N07718)**

4.1 Process Control Requirements

4.1.1 Chemical Composition Requirements

4.1.1.1 Chemical Composition Limits

The chemical composition shall conform to the weight percent requirements ~~of UNS N07718 as modified below presented in Table 1.~~

Table 1 – Chemical Composition

Element	UNS Number					
	N07716	N07718 ^a	N07725	N09925	N09935	N09945 ^c
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	45.0 to 55.0
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
Fe ^a	Bal.	Bal.	Bal.	22 min	Bal.	Bal.
Nb	2.75 to 4.00		2.75 to 4.00	0.50 max	0.20 to 1.00	2.80 to 4.50
Cb(Nb) + Ta	-	4.87 to 5.20		0.08 to 0.50	0.20 to 1.00	
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
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
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
C	0.030 max	0.045 max	0.030 max	0.025 max	.030 max	0.005 to 0.040
Co	-	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
Si	0.20 max	0.35 max	0.20 max	0.35 max	0.35 max	0.50 max
P	0.015 max	0.010 max	0.015 max	0.020 max	0.025 max	0.030 max
S	0.010 max	0.010 max	0.010 max	0.003 max	0.001 max	0.010 max
B	0.006 max	0.0060 (60 ppm) max	-			
Cu	0.23 max	0.23 max	-	1.50 to 3.00	1.00 to 2.00	1.50 to 3.00
Pb	0.001 max	0.0010 (10 ppm) max	-	-	-	-
Se	-	0.0005 (5 ppm) max	-	-	-	-

Ca ^b	-	0.0030 (30 ppm) max	-	-	-	-
Mg ^b	-	0.0060 (60 ppm) max	-	-	-	-
W					1.00 max	

^aShall be determined arithmetically by difference or by direct measurement.

^bTo be determined if intentionally added.

^c For UNS N09945, material designation 125K, it is recommended that the chemistry be modified to 46.5 to 48.0 Ni and 2.80 to 3.50 Nb. For UNS N09945 material designation 140K, it is recommended that the chemistry be modified to 52.0 to 55.0 Ni and & 3.80 to 4.50 Nb.

4.1.1.2 Chemical Composition Frequency and Test Methods

The chemical composition shall be tested on a remelt ingot basis on product representative of a remelt ingot per ASTM E 354, ASTM E 1473 or a nationally or internationally recognized industry standard.

4.1.1.3 Check (Product) Analysis

When material is qualified by the use of a check (product) analysis performed on either the test coupon or a non-critical area of the production material, the analysis shall conform to the check (product) analysis variation specified in ASTM B 880.

4.1.2 Melt Practice Requirements

4.1.2.1 Acceptable Melt Practices

The alloy shall be melted by one of the following sequences of processes:

4.1.2.1.1 UNS N07718, one of the following sequences of processes shall be followed:

- a) Step 1—Basic electric furnace (EF).
Step 2—Either argon oxygen decarburization (AOD) or vacuum oxygen decarburization (VOD).
Step 3—Vacuum arc remelting (VAR).
Step 4—VAR.

or:

- b) Step 1—Vacuum induction melting (VIM).
Step 2—Either electroslag remelting (ESR), electroflux remelting (EFR) or vacuum arc remelting (VAR).
Optional Step 3—ESR or EFR or VAR.

4.1.2.1.2 UNS N09925, UNS N09935 and UNS N09945, one of the following sequences of processes shall be followed:

- a) Step 1—Basic electric furnace (EF).
Step 2—Either argon oxygen decarburization (AOD), vacuum oxygen decarburization (VOD) or vacuum degassing.
Step 3—Either electroslag remelting (ESR), electroflux remelting (EFR) or vacuum arc remelting (VAR).
Optional Step 4—VAR

or:

- b) Step 1—Vacuum induction melting (VIM).

Step 2—Either electroslag remelting (ESR), electroflux remelting (EFR) or vacuum arc remelting (VAR).
Optional Step 3—VAR

4.1.2.1.3 UNS N07716 and UNS N07725, one of the following sequences of processes shall be followed:

a) Step 1—Basic electric furnace (EF).
Step 2—Either argon oxygen decarburization (AOD) or vacuum oxygen decarburization (VOD).
Step 3—Vacuum arc remelting (VAR).
Optional Step 4—VAR.

or:

b) Step 1—Vacuum induction melting (VIM).
Optional Step 2— Electroslag remelting (ESR) or electroflux remelting (EFR)
Step 3—Vacuum arc remelting (VAR).
Optional Step 4—VAR.

4.1.3 Forging and Hot Working Requirements

4.1.3.1 Hot Work Reduction Ratio

The minimum total hot work reduction ratio shall be 4:1

4.1.4 Heat Treating Requirements

4.1.4.1 Heat Treating Equipment Qualification and Calibration

The practice for qualification of heat-treating equipment shall be per the API Specification 6A Annex for qualification of heat-treating equipment, AMS 2750 or another internationally recognized standard. Furnace instrumentation shall be calibrated at least every 3 months. Furnaces shall be ~~calibrated~~ surveyed no less than once a year ~~or when a furnace is moved, repaired or rebuilt~~. When a furnace is moved, repaired or rebuilt refer to API6A for survey requirements. When the API Specification 6A Annex for qualification of heat-treating equipment is selected as the basis for furnace calibration, the requirements of the API Specification 6A Annex shall be treated as Normative.

4.1.4.2 Temperature Monitoring

The material temperature shall be measured by use of either a contact surface thermocouple or a heat sink as described in API Spec 6A or ISO 10423. The hold time shall not commence until the contact surface thermocouple or a heat sink reaches at least the minimum required material temperature.

The material manufacturer or material supplier shall maintain copies of the heat treating charts showing the material temperature as measured by the contact surface thermocouple or heat sink for 5 years minimum following the date of heat treatment.

4.1.4.3 Solution Annealing and Age Hardening

The production material and QTC(s) shall be solution annealed and age hardened in accordance with the ~~following procedure.~~ procedures in Table 2.

Table 2 – Heat Treatment Procedures

UNS	Material Designation	Solution Annealing		Age Hardening ^b
		Material Temperature	Time (hours)	Material Temperature and Time
N07716	120K	1875°F - 1925°F (1024°C - 1052°C)	0.5 to 4 ^b	1310°F - 1455°F (710°C - 790°C) for 4-9 hours, furnace cool to 1125°F - 1275°F (607°C - 690°C) and hold for total ageing time of 12 hours minimum
N07716	140K	1875°F - 1925°F (1024°C - 1052°C)	0.5 to 4 ^b	1310°F - 1455°F (710°C - 790°C) for 4-9 hours, furnace cool to 1125°F - 1275°F (607°C - 690°C) and hold for total ageing time of 12 hours minimum
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
N07718	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
N07725	120K	1875°F - 1950°F (1024°C - 1065°C)	0.5 to 4 ^b	1325°F -1425°F(720°C - 774°C) for 4 - 9 hours, furnace cool to 1125°F - 1275°F (607°C - 690°C) and hold for total ageing time of 12 hours minimum
N09925	110K	1825°F - 1925°F (996°C - 1052°C)	0.5 to 4 ^a	1325°F -1400°F(720°C - 760°C) for 4- 9 hours, furnace cool to 1125°F-1220°F (607°C- 660°C) and hold for total ageing time of 12 hours minimum
N09935	110K	1870°F - 1975°F (1021°C - 1080°C)	0.5 to 4 ^a	1345°F-1435°F (730°C-780°C) for 4-9 hours, furnace cool to 1165°F-1255°F (630°C-680°C) and hold for total ageing time of 12 hours minimum
N09945	125K	1800°F - 1950°F (996°C - 1065°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 ageing time of 12 hours minimum
N09945	140K	1800°F - 1950°F (996°C - 1065°C)	0.5 to 4 ^a	1250°F-1350°F (677°C-732°C) for 6 -9 hours, furnace cool to 1110°F-1190°F (599°C-643°C) and hold for total ageing time of 18 hours minimum
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.				

Optional Re-heat Treatment Steps—Complete re-heat treatment is permitted. Alternatively, re-aging within the parameters in ~~Step 3~~ of Table 2 is permitted, provided the cumulative aging time does not exceed the maximum allowable aging time. All other requirements of shall be met by material that has been subjected to either of these optional steps.

If the material is re-aged without re-resolution annealing, the testing required by Sections 4.2.2, 4.2.3, 4.2.4, and 4.2.5 may be performed on remnants of the original QTC, provided the remnants are re-aged with the production material they represent.

4.2 TESTING REQUIREMENTS

4.2.1 Macroetch Requirements

4.2.1.1 Test Location, Method and Frequency

A macroetch examination shall be performed. The macroetch examination shall be performed on either (a) or (b) as shown below:

a. Full transverse cross-section slices representative of the top and bottom of each final remelt ingot or product thereof.

b. For product not tested by the mill and not identified as to its relative location within the ingot, the macroetch testing shall be performed on a per billet, bar or other raw material product form basis. A full transverse cross-section slice shall be examined from each end.

The full cross section slices shall be etched for examination. The acceptable etchants are as follows:

Option A: Canada's Etchant 100 ml H₂SO₄, 100 ml HF, 50 ml HNO₃, 400 ml H₂O

Etch at 160°F – 180°F (71°C – 82°C)

Option B: Aqua Regia 200 ml HCl, 100 ml HNO₃

Option C: Kalling's Etchant 200 ml Methanol, 200 ml HCl, 10 g CuCl₂

Option D: Hydrochloric—Peroxide H₂O₂ (30%) 100 ml, HCl 200 ml, H₂O 300 ml

Remove stains with 50% HNO₃

Option E: Dilute Heated Aqua Regia 250 ml HCl, 10- 20 ml HNO₃

Etch at 140°F – 165°F (60°C – 74°C)

4.2.1.2 Macroetch Examination and Acceptance Criteria

The macrostructure of the slice shall be examined and rated to all four classes in ASTM A 604. The acceptance criteria are as follows:

Class 1 (Freckles)—No worse than Severity A

Class 2 (White Spots)—No worse than Severity A

Class 3 (Radial Segregation)—No worse than Severity A

Class 4 (Ring Pattern)—No worse than Severity A

4.2.2 Microstructural Analysis Requirement

4.2.2.1 Test Location, Method and Frequency

Sample(s) of material with the same shape and equivalent round from each remelt ingot per heat treat lot shall be subjected to a microstructural analysis.

The sample(s) to be examined shall be a minimum ¹/₄ in. (6 mm) square and oriented longitudinally to the primary axis of grain flow. If the cross section of the material is less than ¹/₄ in. (6 mm), then the sample(s) shall be full cross section. The microstructural analysis shall be performed on material in the final heat treatment condition. Test locations shall be a minimum of 1.25 in. (32 mm) from a heat treated end surface.

For solid material, the center, $\frac{1}{4}$ thickness and surface locations shall be evaluated. For hollow material, the mid-wall location and both the inner and outer surfaces shall be evaluated.

The microstructural samples shall be etched for examination. The acceptable etchants are as follows:

All Alloys	Option A: Kalling's No. 2 or Waterless Kalling's	200 ml Methanol, 200 ml HCl, 10 g CuCl ₂
	Option B: Super Kalling's	5 ml H₂O₂, 60 ml HCl, 6 g CuCl₂
All Alloys	Option C B: Seven acids	300 ml HCl, 60 ml HNO ₃ , 60 ml H ₃ PO ₄ , 30 ml 40% HF, 30 ml H ₂ SO ₄ , 30 g FeCl ₃ (anhydrous), 60 ml CH ₃ COOH, 300 ml H ₂ O
All Alloys	Option C: Diluted Glyceregia	10 ml glycerol, 150 ml HCl, 15 ml HNO ₃
UNS N09925, UNS N09935 UNS N07725, UNS N07716	Option D: Bromine-Methanol	Clean in HCl before etching in immersed 1-3% Bromine, Methanol
UNS N09925	Option E: Nitric-HCl	10 ml HNO ₃ , 60 ml HCl

The material manufacturer or material supplier shall retain the metallographic specimen mounts for 5 years minimum following the date of the examination.

4.2.2.2 Grain Size Evaluation

4.2.2.2.1 Grain Size

The average grain size shall be determined in accordance with ASTM E 112. The ASTM average grain size shall be No. 2 or finer.

4.2.2.2.2 Duplex Grain Size

No topological duplex grain size as defined and measured per ASTM E 1181 is allowed.

4.2.2.3 Metallographic Examination for Deleterious Phases

The microstructural samples shall be examined for deleterious phases. The microstructural samples shall be examined at 100X and 500X using light microscopy.

The acceptance criteria are as follows:

- a. The microstructure for all alloys shall be free from acicular phases except in individual, isolated grains that are not representative of the bulk of the microstructure. In no case shall any individual grain be surrounded with acicular phases.
- b. ~~UNS N07718, The~~ microstructures shall be free from continuous networks of secondary phases along grain boundaries ~~or other unusual microstructural features~~, except for individual, isolated grains that are not representative of the bulk of the microstructure. The presence of discrete, isolated particles of ~~delta~~ secondary phases or carbides is acceptable.
- c. There shall be no laves phase.

Note: Examination of the microstructural samples for laves phase is not required if the final melt source certifies that the material is free from laves phase.

The Reference Photomicrographs in Annex A are examples of acceptable and unacceptable microstructures.

Material that is rejected for unacceptable microstructural features may be fully re-heat treated (solution annealed and age hardened) in accordance with 4.1.4 and re-examined.

If a heat treat lot is rejected, then the other pieces within the heat treat lot may be qualified on an individual piece basis **if both ends are examined and meet the microstructural requirements**. Material containing rejectable metallographic locations may be accepted if the rejectable locations will be removed by machining.

4.2.3 Tensile Property Requirements

4.2.3.1 Test Location, Method and Frequency

One tensile test shall be performed for each tested QTC. **The test frequency shall be one test per remelt ingot per heat treat lot (batch) (as defined in API Spec 6A and ISO 10423) for material of the same size.**

The QTC shall be either a prolongation (full cross section on thickest end) or sacrificial production part.

For solid material, the test specimen shall be removed from a location at $1/4$ thickness or deeper from the side or outer diameter and at least 1.25 in. (32 mm) from the end. For hollow material, the test specimen shall be removed from a mid-wall location and at least 1.25 in. (32 mm) from the end.

The test specimen and test method shall be in accordance with ASTM A 370.

4.2.3.2 Tensile Test Acceptance Criteria

The tensile properties shall meet the acceptance criteria as shown in Table 3.

Table 3 – Tensile Requirements

UNS number	Material Designation	QTC Cross ^a Section Thickness in. (cm) ^a	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(25.4)	120(827)	150(1034)	150(1034)	20	35
		>10(25.4)	120(827)	150(1034)	150(1034)	20	25
	140K	≤10(25.4)	140(965)	160(1103)	165(1138)	18	30
		>10(25.4)	140(965)	160(1103)	165(1138)	18	20
N07718	120K	≤10(25.4)	120(827)	145 (1000)	150(1034)	20	35
		>10(25.4)	120(827)	145 (1000)	150(1034)	20	25
	140K	≤10(25.4)	140(965)	150 (1034)	165(1138)	20	35
		>10(25.4)	140(965)	150 (1034)	160(1103)	20	25
N07725	120K	≤10(25.4)	120(827)	150(1034)	150(1034)	20	35
		>10(25.4)	120(827)	150(1034)	150(1034)	20	25
N09925	110K	≤10(25.4)	110(758)	140(965)	140(965)	18	25
		≤10(25.4)	110(758)	140(965)	140(965)	18	20
N09935	110K	>10(25.4)	110(758)	140(965)	140(965)	18	25
		>10(25.4)	110(758)	140(965)	140(965)	18	20
N09945	125K	≤10(25.4)	125(862)	155(1068)	150(1034)	18	25
		>10(25.4)	125(862)	155(1068)	150(1034)	18	20
N09945	140K	≤10(25.4)	140(965)	165(1138)	165(1138)	18	25
		>10(25.4)	140(965)	165(1138)	165(1138)	18	20

a- QTC cross section thickness at time of heat treatment

4.2.3.3 Retesting

If the results of the tensile test(s) do not satisfy the applicable requirements, two additional tests on two additional specimens (removed from the same QTC with no additional heat treatment) may be performed in an effort to qualify the material. The results of each of these tests shall satisfy the applicable requirements.

4.2.4 Impact Toughness Requirements

4.2.4.1 Test Location, Method and Frequency

Charpy V-notch impact testing shall be performed on all material in accordance with ASTM A 370. All tests shall be performed at or below -75°F (-60°C) regardless of API Spec 6A ~~or ISO 10423~~ Temperature Classification.

Impact testing shall be performed on a set of three specimens. Specimens oriented transverse to the primary direction of grain flow shall be used unless the size or geometry of the QTC prevents the usage of transverse specimens (material less than 3 in. [76 mm] in cross section). When transverse specimens cannot be used for these reasons, longitudinal specimens shall be used.

One set of Charpy V-notch impact tests shall be performed for each tested QTC. The test frequency shall be one set of tests per heat per remelt ingot per heat treat lot (batch) (as defined in API Spec 6A ~~and ISO 10423~~) for material of the same size.

The QTC shall be either a prolongation (full cross section on thickest end) or sacrificial production part.

For solid material, the test specimens shall be removed from a location at $1/4$ thickness or deeper from the side or outer diameter and at least 1.25 in. (32 mm) from the end. For hollow material, the test specimens shall be removed from a mid-wall location from the side and at least 1.25 in. (32 mm) from the end.

The test specimens and test method shall be in accordance with ASTM A 370.

4.2.4.2 Charpy V-notch Acceptance Criteria

The average energy value for a set of three specimens shall meet or exceed the specified average. No more than one of the specimens shall have an energy value below the specified average and it shall not be below the specified single minimum. No specimens shall have a lateral expansion below the specified value.

The adjustment factors for sub-size impact specimens in API Spec 6A shall apply to the absorbed energy values for all PSLs. Lateral expansion shall be as stated in the Table 4 regardless of specimen size.

Table 4 – Charpy V-notch Impact Toughness Requirements (10 mm x 10mm)

N07716	120K	<3(7.6)	L	40(54)	35(47)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	37(50)	32(43)	0.015(0.38)
		>10(25.4)	T	32(43)	27(34)	0.015(0.38)
	140K	<3(7.6)	L	40(54)	35(47)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	30(41)	27(37)	0.015(0.38)
		>10(25.4)	T	30(41)	27(37)	0.015(0.38)
N07718	120K	<3(7.6)	L	50(68)	45(61)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	35(47)	30(41)	0.015(0.38)
		>10(25.4)	T	30(41)	27(37)	0.015(0.38)
N07718	140K	<3(7.6)	L	50(68)	45(61)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	35(47)	30(41)	0.015(0.38)
		>10(25.4)	T	30(41)	27(37)	0.015(0.38)

N07725	120K	<3(7.6)	L	40(54)	35(47)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	37(50)	32(43)	0.015(0.38)
		>10(25.4)	T	32(43)	27(34)	0.015(0.38)
N09925	110K	<3(7.6)	L	35(47)	32(43)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	35(47)	32(43)	0.015(0.38)
		>10(25.4)	T	35(47)	32(43)	0.015(0.38)
N09935	110K	<3(7.6)	L	35(47)	30(41)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	30(34)	25(27)	0.015(0.38)
		>10(25.4)	T	25(34)	20(27)	0.015(0.38)
N09945	125K	<3(7.6)	L	50(68)	45(61)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	40(54)	35(47)	0.015(0.38)
		>10(25.4)	T	30(41)	27(34)	0.015(0.38)
	140K	<3(7.6)	L	45(61)	40(54)	0.015(0.38)
		>=3(7.6) thru 10(25.4)	T	35(47)	30(41)	0.015(0.38)
		>10(25.4)	T	30(41)	27(34)	0.015(0.38)

a- QTC cross section thickness at time of heat treatment

4.2.4.3 Retesting

If a test fails, then a retest of three additional specimens removed from the same QTC with no additional heat treatment may be made, each of which shall exhibit an impact value equal to or exceeding the minimum average value.

4.2.5 Hardness Test Requirements

4.2.5.1 Test Location, Method and Frequency

- a. Each piece of production material shall be hardness tested on or near the surface using the Rockwell C method per ASTM E 18 or the Brinell (10 mm ball, 3000 kgf) method per ASTM E 10 after the final heat treatment cycle. For Rockwell C-scale testing three adjacent indentations shall be made and the mean hardness reported. No individual hardness number may be greater than 2 HRC units above the maximum specified hardness number. For Brinell testing at least one indentation shall be made. In case of dispute, the Rockwell C-scale method shall be the referee method.
- b. Cross-section hardness testing shall be performed on each QTC using the Rockwell C method per ASTM E 18. Three adjacent indentations shall be made near the surface, three adjacent indentations shall be made at ¼ thickness and three adjacent indentations at the center. The mean hardness at each location shall be reported. No individual hardness number may be greater than 2 HRC units above the maximum specified hardness number.

4.2.5.2 Hardness Test Acceptance Criteria

The hardness tests shall meet the acceptance criteria shown in Table 5.

Table 5 –Mean Hardness Requirements^a

UNS number	Material Designation	Minimum Hardness HRC (HBW)	Maximum Hardness HRC (HBW)
N07716	120K	32 (298)	40 (363)
	140K	34 (313)	43 (392)
N07718	120K	32 (298)	40 (363)
	140K	34 (313)	40 (363)

N07725	120K	32 (298)	40 (363)
N09925	110K	26 (259)	38 (346)
N09935	110K	24 (250)	34 (313)
N09945	125K	32 (298)	42 (382)
	140K	34 (313)	42 (382)

a – hardness results below the minimum hardness limit is not the sole basis for rejection. If an adjacent tensile specimen is taken and passes tensile test requirements the material is acceptable.

4.2.5.3 Retests

If any hardness requirements are not met, three additional indentations shall be made in the immediate area to determine new hardness numbers. If each new hardness number meets the requirements of this International Standard, then the length is qualified.

If one or more new hardness numbers fail, then the length is rejected. At the manufacturer's option, the rejected length may be qualified by performing cross-section hardness tests in accordance with 4.2.5.1b.

4.2.6 Nondestructive Examination

The nondestructive examination requirements in API Spec 6A ~~or ISO 10423~~ shall apply as required for the specified component type and PSL specified on the purchase order.

5 Certification

The material supplier shall provide a certified test report to the equipment manufacturer containing the following information as a minimum:

- 5.1 Chemical analysis results (see 4.1.1)
- 5.2 Melt practice utilized (see 4.1.2)
- 5.3 Name of melt source
- 5.4 Name of ~~company facility~~ performing the hot working operations (if different from melt source)
- 5.5 Name of ~~company facility~~ performing the heat treatment (if different from melt source)
- 5.6 Total hot work reduction ratio (see 4.1.3)
- 5.7 Actual heat treatment times and temperatures and cooling media (see 4.1.4)
- 5.8 Name of test laboratory
- 5.9 Statement that the material complies with the requirements of the macroetch examination (see 4.2.1)
- 5.10 ~~Average Predominant~~ grain size (see 4.2.2)
- 5.11 Statement of compliance with topological duplex grain size testing requirement (see 4.2.2)
- 5.12 Statement that the material complies with the requirements of the metallographic examination for deleterious phases (see 4.2.2)
- 5.13 A set of legible photomicrographs (see 4.2.2.3)
- 5.14 Tensile test results (see 4.2.3)

5.15 Impact test temperature, orientation, and results (see 4.2.4)

5.16 Hardness test results (see 4.2.5)

5.17 NDE results, if performed (see 4.2.6)

6 Marking

The raw material shall be marked or tagged with identification traceable to the certification **for the remelt ingot and heat treat lot.**

ANNEX A