AEROSPACE MATERIAL SPECIFICATION

AMS2759™/1	REV. J

Issued 1984-10
Reaffirmed 2014-04
Revised 2021-08

Superseding AMS2759/1H

Heat Treatment of Carbon and Low-Alloy Steel Parts Minimum Tensile Strength Below 220 ksi (1517 MPa)

RATIONALE

AMS2759/1J adds clarification to surface contamination (3.5.2.1) and to periodic test (4.2) regarding Type 1 parts; adds reference to a new note 8.6 in surface contamination (3.5.2.1); separates hardness and surface contamination in acceptance tests (4.1); adds reference to new note 8.7 in acceptance tests (4.1); adds new notes 8.6 and 8.7; updates Tables 2 and 3 to include specific alloys that were listed in Table 6, but inadvertently left out; corrects Table 4 to delete a line separating alloys that should not have been there; corrects Table 6 by moving 4137 to be in line with 4135 and 8735.

NOTICE

ORDERING INFORMATION: In addition to that listed in AMS2759, the purchaser shall supply the following information to the heat treating processor.

- AMS2759/1J
- Whether the parts are “damage tolerant,” “maintenance critical,” or “fracture critical” (see 3.4.7). These designations have been previously used to designate parts requiring additional inspection (see 4.1).
- Tensile strength or hardness if other than that stated in Tables 3 and 4 (see 3.4.8 and 3.5.1).
- Cognizant engineering organization approval if dimensions at heat treatment exceed Table 6 size limits.

1. SCOPE

This specification, in conjunction with the general requirements for steel heat treatment covered in AMS2759, establishes the requirements for heat treatment of carbon and low-alloy steel parts to minimum ultimate tensile strengths below 220 ksi (1517 MPa). Parts are defined in AMS2759. Due to limited hardenability in these materials, there are size limits in this specification.

1.1 The provisions of this specification revision shall become effective 90 days after publication.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
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For more information on this standard, visit
https://www.sae.org/standards/content/AMS2759/1J

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2418 Plating, Copper

AMS2424 Plating, Nickel, Low-Stressed Deposit

AMS2750 Pyrometry

AMS2759 Heat Treatment of Steel Parts, General Requirements

3. TECHNICAL REQUIREMENTS

3.1 Heat Treatment

Shall conform to AMS2759 and the requirements specified herein.

3.2 Equipment

Equipment shall conform to AMS2759. Equipment specifically used for tempering of H-11, D6AC, and 9Ni-4Co steels shall conform to AMS2750, Class 2.

3.3 Heating Environment

Parts shall be controlled by type and heat treated in the class of atmosphere permitted in Table 1 for that type when heating above 1250 °F (677 °C). When heating parts at 1250 °F (677 °C) or below, Class A, B, or C atmosphere may be used (see 8.2). Atmosphere class and part type are described in AMS2759.

Table 1 - Atmospheres

Part Type	Atmosphere Classification		
	Class A	Class B	Class C
Type 1	Permitted	Permitted	Permitted
Type 2	Permitted	PROHIBITED (1)	PROHIBITED

NOTES:
(1) Permitted provided the atmosphere is controlled to meet the surface contamination requirements in 3.5.2.

3.3.1 Protective Coatings

A supplemental coating or plating is permitted when approved by the cognizant engineering organization. Fine grain copper plating in accordance with AMS2418 or nickel plating in accordance with AMS2424 may be used without approval, but the surface contamination specimens in AMS2759 shall not be plated.

3.4 Procedure

3.4.1 Preheating

Preheating until furnace stabilization in the 900 to 1200 °F (482 to 649 °C) range is recommended before heating parts above 1300 °F (704 °C) if the parts have previously been heat treated to a hardness greater than 35 HRC, have abrupt changes of section thickness, have sharp reentrant angles, have finished machined surfaces, have been welded, have been cold formed or straightened, have holes, or have sharp or only slightly rounded notches or corners.

3.4.2 Soaking

The start of soaking time shall be in accordance with AMS2759.

3.4.2.1 Parts coated with copper plate or similar reflective coatings that tend to reflect radiant heat shall have their soak time increased by at least 50% unless load thermocouples are used. This increase does not apply to salt bath heat treating, tempering, or sub-zero processing.

3.4.3 Annealing

3.4.3.1 When required, annealing shall be accomplished by heating to the set temperature specified in Table 2, soaking for the time specified in Table 5, and cooling to below the temperature specified in Table 2 at the rate shown in Table 2 followed by air cooling to ambient temperature. Isothermal annealing treatments may be used provided equivalent hardness is obtained.

3.4.3.2 Isothermal annealing shall be accomplished by heating to the annealing set temperature specified in Table 2, soaking for the time specified in Table 5, cooling to a temperature below the critical holding for sufficient time to complete transformation, and air cooling to ambient temperature.

3.4.4 Subcritical Annealing

When required, subcritical annealing shall be accomplished prior to hardening by heating to a set temperature between 1150 and 1250 °F (621 and 677 °C), soaking for the time specified in Table 5, and cooling to ambient temperature. Steel parts of the 9Ni-4Co type shall be subcritical annealed as specified in Table 2.

3.4.5 Pre-Hardening Stress Relief

When required, pre-hardening stress relieving shall be done in accordance with AMS2759/11 prior to hardening by heating to a set temperature between 1000 and 1250 °F (538 to 677 °C), soaking for not less than the time specified in Table 5 and cooling to ambient temperature.

3.4.6 Normalizing

When required, normalizing shall be accomplished by heating to the set temperature specified in Table 2, soaking for the time specified in Table 5, and cooling in air or atmosphere to ambient temperature. Circulated air or atmosphere is recommended for thicknesses greater than 3 inches (76 mm). Normalizing may be followed by tempering or subcritical annealing.

3.4.7 Hardening (Austenitizing and Quenching)

3.4.7.1 When required, hardening shall be accomplished by heating to the set temperature stated in Table 2, soaking for the time stated in Table 5, and quenching as stated in Table 2. The parts shall be cooled to or below the quenchant temperature, or to a temperature low enough to achieve complete transformation, before tempering. Parts may be gas quenched provided they have been qualified per Appendix A or in accordance with another procedure approved by the cognizant engineering organization. The alloy, part size, and load size shall be qualified prior to processing hardware. Prior to initial tempering parts may be snap tempered for 2 hours minimum at a temperature, usually 400 °F (204 °C), that is lower than the tempering temperature (see 8.4.1).

3.4.7.2 As steel parts hardened to this specification have limited hardenability, which varies by alloy, the size limits in Table 6 shall apply. Parts exceeding size limitations shall be machined to within 0.125 inch (3.2 mm) of the final dimensions prior to hardening. With cognizant engineering organization approval, parts may be greater than 0.125 inch (3.2 mm) of the final dimensions prior to hardening.

3.4.7.3 Welded parts, and brazed parts with a brazing temperature above the normalizing temperature, shall be normalized before hardening. For welded or brazed alloys that are not normalized (for example H-11; see Table 2), the parts shall be annealed. Welded parts should be preheated in accordance with 3.4.1. Parts identified as damage tolerant, maintenance critical, or fracture critical shall be in the normalized condition before hardening, unless the alloy is not normalized (see Table 2), in which case the part shall be annealed.

3.4.8 Tempering

When required, tempering shall be accomplished by heating quenched parts to the set temperature required to produce the stated properties. Parts should be tempered within 2 hours of quenching. Suggested tempering temperatures for specific tensile strengths and hardnesses for each alloy and quenchant are shown in Table 3. Alternate tempering temperatures for specific alloys, based on as-quenched hardness, are shown in Table 4. Soaking time shall be not less than 2 hours plus 1 hour additional for each inch (25 mm) of thickness or fraction thereof greater than 1 inch (25 mm). Thickness is defined in AMS2759. When load thermocouples are used, the soaking time shall be not less than 2 hours. Multiple tempering cycles are permitted. When multiple tempering cycles are required, parts shall be cooled to ambient temperature between tempering treatments (see Table 3).

3.4.8.1 When tempering cannot be started within 4 hours from the end of quenching, parts shall be snap tempered for 2 hours minimum at a temperature that is lower than the final tempering set temperature (see 8.4.1); usually 400 °F (204 °C).

3.4.9 Straightening

For parts having minimum tensile strength below 180 ksi (1241 MPa), straightening may be accomplished cold without stress relieving. For parts hardened and tempered to minimum tensile strength of 180 ksi (1241 MPa) and higher, straightening shall be accomplished during tempering, or by heating to not higher than 50 °F (28 °C) below the tempering temperature. Hot or warm straightening after tempering shall be followed by stress relieving. It is permissible to retemper at a temperature not higher than the last tempering temperature after straightening during tempering.

3.5 Properties

3.5.1 Hardness

Parts shall conform to the specified hardness or the hardness converted from the tensile strength ranges stated in Table 3 or the hardness converted from the tensile strength ranges stated in Table 4 as applicable. Hardness testing shall not be used to reject parts that meet specified tensile properties. Frequency of hardness testing shall be in accordance with AMS2759.

3.5.2 Surface Contamination

Shall be in accordance with AMS2759, except partial decarburization shall not exceed 0.005 inch (0.13 mm).

3.5.2.1 Parts that will be machined after heat treatment, but that will have less than 0.020 inch (0.51 mm) of metal removed from any machined surface, i.e., Type 2 parts, may be reclassified as Type 1 parts and need not meet the requirements of 3.5.2 as heat treated, when it is demonstrated by tests on each load that all surface contamination exceeding the requirements of 3.5.2 will be removed from all machined surfaces, taking into account distortion after heat treatment (see 8.6).

3.5.2.2 The heat treating processor shall be responsible for determining whether cumulative heat treating operations at their facility have caused surface contamination in excess of that allowed.

3.6 Test Methods

Shall be in accordance with AMS2759.

4. QUALITY ASSURANCE PROVISIONS

The responsibility for inspection, classification of tests, sampling and testing, approval, records, record retention, and report/certification shall be in accordance with AMS2759 and as follows.

4.1 Acceptance Tests

Hardness (3.5.1) is an acceptance test and shall be performed on each lot. Surface contamination (3.5.2) on damage tolerant, maintenance critical, or fracture critical parts is an acceptance test and shall be performed on each lot (see 8.7).

4.2 Periodic Tests

In addition to the tests specified in AMS2759, tests for surface contamination (3.5.2) shall be performed monthly on each furnace in service, each kind of atmosphere to be used in each furnace, and for each Class B atmosphere at two carbon potentials, up to 0.40% and over 0.40%. Furnaces used exclusively to heat treat parts that will have all contamination removed, i.e., Type 1 parts, shall not require testing.

4.3 Preproduction Tests

In addition to the tests specified in AMS2759, tests for surface contamination (3.5.2) shall be performed prior to any production heat treating on each furnace, each kind of atmosphere to be used in each furnace, and for each Class B atmosphere at two carbon potentials, up to 0.40% and over 0.40%. Furnaces used exclusively to heat treat parts that will have all contamination removed, i.e., Type 1 parts, shall not require testing.

5. PREPARATION FOR DELIVERY

Shall be in accordance with AMS2759.

6. ACKNOWLEDGMENT

Shall be in accordance with AMS2759.

7. REJECTIONS

Shall be in accordance with AMS2759.

8. NOTES

Shall be in accordance with AMS2759 and the following.

NOTICE

This specification may reference the use of substances, products, or processes that are restricted or banned by local (regional) chemical substance regulations. Users of this specification should consider the implications of local legislation on the products, substances, and processes referred to within the document.

8.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

8.2 Heating below 1400 °F (760 °C) with Class B atmospheres containing 5% or more of hydrogen (H_2), carbon monoxide (CO), or methane (CH_4), may result in explosion and fire.

8.3 Use of a chromic-caustic etch to reveal intergranular attack/oxidation has been discontinued because (1) it is an environmental hazard, (2) it is unnecessary for measurement of maximum depth of crevices, and (3) light etching zones extending beyond the crevices have been misinterpreted as manifestations of intergranular oxidation.

8.4 Terms used in AMS are clarified in ARP1917 and as follows:

8.4.1 Snap tempering is an intermediate low temperature treatment to relieve stresses and prevent cracking prior to the next operation. Final tempering to the specified requirements is performed after snap tempering.

8.5 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and the Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.6 This allows the maker of these parts and the heat treater to pre-plan dimensions for adequate removal of decarburization without being constrained by atmosphere limits and leaving less than 0.020 inch (0.51 mm) stock to clean up. This also reflects the surface contamination requirement in AMS2759.

8.7 The terms “damage tolerant,” “maintenance critical,” or “fracture critical” are typically referenced on engineering drawings by the design authority.

Table 2A - Annealing, normalizing, and austenitizing set temperatures and quenchants (inch/pound units)

Material Designation	Annealing [1] Temperature, °F	Normalizing Temperature, °F	Austenitizing Temperature, °F	Hardening Quenchant
1025	1625	1650	1600	water, polymer
1035	1600	1650	1550	oil, water, polymer
1045	1575	1650	1525	oil, water, polymer
1065	1550	1600	1500	oil, polymer
1070	1525	1600	1500	oil, polymer
1074	1525	1600	1500	oil, polymer
1095 [2]	1500	1550	1475	oil, polymer
1137	1450	1650	1550	oil, water, polymer
3140	1500	1650	1500	oil, polymer
4037	1550	1650	1550	oil, water, polymer
4130	1550	1650	1575	oil, water, polymer
4135	1550	1650	1575	oil, polymer
4137	1550	1650	1575	oil, polymer
4140	1550	1650	1550	oil, polymer
4150	1525	1600	1525	oil, polymer
4330V, 4330Mod	1550-1575 [8]	1650	1600	oil, polymer
4335V, 4335Mod	1550	1650	1600	oil, polymer
4340	1550	1650	1500-1550[8]	oil, polymer
4640	1550	1650	1525	oil, polymer
6150	1550	1650	1600	oil, polymer
8630	1550	1650	1575	oil, water, polymer
8735	1550	1650	1550	oil, polymer
8740	1550	1650	1550	oil, polymer
H-11 [3]	1600	[9]	1850	air, oil, polymer
98BV40 Modified	1550	1600	1550	oil, polymer
D6AC [4]	1550	1725	1625 [5]	oil, polymer
9Ni-4Co-0.20C	[6]	1650	1525	oil, water, polymer [7]
9Ni-4Co-0.30C	[6]	1700	1550	oil, polymer [7]
Nitralloy 135 Mod	1275	1800	1725	oil, polymer
Nitralloy EZ	1275	1800	1725	oil, polymer
Nitralloy N	1275	1750	1650	oil, polymer
AMS6494, 6495 FND, FNDW	1274-1364 [8]	1742-1832 [8]	1706-1796 [8]	air, oil, polymer
AMS6492, 6493 FDG, FDGW	1202-1274 [8]	1652-1742 [8]	1508-1598 [8]	air, oil, polymer
AMS6481 GKHYW	1310-1400 [8]	1688-1778 [8]	1652-1742 [8]	oil, polymer
AMS6497, 6498 GKPW, GKPYW	1562-1634 [8]	1652-1742 [8]	1670-1742 [8]	oil, polymer
AMS6547, 6548, 6549 FADH, FADHW, FADHYW	1202-1274 [8]	1652-1742 [8]	1508-1598 [8]	oil, polymer

NOTES:

[1] Temperature 1300 °F and above are to be cooled at a rate not to exceed 200 °F per hour to below 1000 °F, except 4330V, 4335V, and 4340 to below 800 °F, and 4640 to below 750 °F. Temperatures below 1300 °F are sub-critical annealing treatments and are air cooled to room temperature.

[2] 1095 parts should be spheroidize annealed before hardening.

[3] H-11 parts shall be in the annealed condition prior to the initial austenitizing treatment, except hot handled parts shall be annealed at 1625 °F and furnace cooled at 50 °F per hour maximum to at least 1000 °F.

[4] D6AC parts shall be in the normalized or the normalized and tempered condition prior to the initial austenitizing treatment, except that parts only normalized without tempering shall be preheated prior to austenitizing.

[5] 1700 °F permitted for D6AC parts when approved by the cognizant engineering organization.

[6] 9Ni-4Co parts shall be duplex subcritical annealed by heating at 1250 °F for 4 hours ± 1/4 hour, air cooling to ambient temperature, reheating at 1150 °F for 4 hours ± 1/4 hour, and air cooling to ambient temperature or shall be annealed by heating at 1150 °F for not less than 23 hours and air cooling to ambient temperature.

[7] Immediately after quenching 9Ni-4Co parts to below 140 °F, subzero cool parts at -90 °F or lower, hold for not less than 1 hour, and air warm to room temperature.

[8] Denotes a range. Any setpoint within this range is acceptable.

[9] These operations are not recommended.

Table 2B - Annealing, normalizing, and austenitizing set temperatures and quenchants (SI units)

Material Designation	Annealing [1] Temperature, °C	Normalizing Temperature, °C	Austenitizing Temperature, °C	Hardening Quenchant
1025	885	899	871	water, polymer
1035	871	899	843	oil, water, polymer
1045	857	899	829	oil, water, polymer
1065	843	871	816	oil, polymer
1070	829	871	816	oil, polymer
1074	829	871	816	oil, polymer
1095 [2]	816	843	802	oil, polymer
1137	788	899	843	oil, water, polymer
3140	816	899	816	oil, polymer
4037	843	899	843	oil, water, polymer
4130	843	899	857	oil, water, polymer
4135	843	899	857	oil, polymer
4137	843	899	857	oil, polymer
4140	843	899	843	oil, polymer
4150	829	871	829	oil, polymer
4330V, 4330Mod	843-857 [8]	899	871	oil, polymer
4335V, 4335Mod	843	899	871	oil, polymer
4340	843	899	816-843 [8]	oil, polymer
4640	843	899	829	oil, polymer
6150	843	899	871	oil, polymer
8630	843	899	857	oil, water, polymer
8735	843	899	843	oil, polymer
8740	843	899	843	oil, polymer
H-11 [3]	871	[9]	1010	air, oil, polymer
98BV40 Modified	843	871	843	oil, polymer
D6AC [4]	843	941	885 [5]	oil, polymer
9Ni-4Co-0.20C	[6]	899	829	oil, water, polymer [7]
9Ni-4Co-0.30C	[6]	927	843	oil, polymer [7]
Nitralloy 135 Mod	691	982	941	oil, polymer
Nitralloy EZ	691	982	941	oil, polymer
Nitralloy N	691	954	899	oil, polymer
AMS6494, 6495 FND, FNDW	690-740 [8]	950-1000 [8]	930-980 [8]	air, oil, polymer
AMS6492, 6493 FDG, FDGW	650-690 [8]	900-950 [8]	820-870 [8]	air, oil, polymer
AMS6481 GKHYW	710-760 [8]	920-970 [8]	900-950 [8]	oil, polymer
AMS6497, 6498 GKPW, GKPYW	850-890 [8]	900-950 [8]	910-950 [8]	oil, polymer
AMS6547, 6548, 6549 FADH, FADHW, FADHYW	650-690 [8]	900-950 [8]	820-870 [8]	oil, polymer

NOTES:

(1) Temperatures 704 °C and above are to be cooled at a rate not to exceed 111 °C per hour to below 538 °C, except 4330V, 4335V, and 4340 to below 427 °C, and 4640 to below 399 °C. Temperatures below 704 °C are sub-critical annealing treatments and are air cooled to room temperature.

(2) 1095 parts should be spheroidize annealed before hardening.

(3) H-11 parts shall be in the annealed condition prior to the initial austenitizing treatment, except hot handled parts shall be annealed at 885 °C and furnace cooled at 28 °C per hour maximum to at least 538 °C.

(4) D6AC parts shall be in the normalized or the normalized and tempered condition prior to the initial austenitizing treatment, except that parts only normalized without tempering shall be preheated prior to austenitizing.

(5) 927 °C permitted for D6AC parts when approved by the cognizant engineering organization.

(6) 9Ni-4Co parts shall be duplex subcritical annealed by heating at 677 °C for 4 hours ± 1/4 hour, air cooling to ambient temperature, reheating at 621 °C for 4 hours ± 1/4 hour, and air cooling to ambient temperature or shall be annealed by heating at 621 °C for not less than 23 hours and air cooling to ambient temperature.

(7) Immediately after quenching 9Ni-4Co parts to below 60 °C, subzero cool parts at -68 °C or lower, hold for not less than 1 hour, and air warm to room temperature.

(8) Denotes a range. Any setpoint within this range is acceptable.

(9) These operations are not recommended.

Table 3A - Suggested tempering temperatures (°F)

Material Designation	Quenchant	Tensile Strength Range ksi [1] 90.0 - 125 Hardness HRB 91-HRC 26	Tensile Strength Range ksi [1] 125 - 150 Hardness HRC 26-34	Tensile Strength Range ksi [1] 150 - 170 Hardness HRC 33-38	Tensile Strength Range ksi [1] 160 - 180 Hardness HRC 36-40	Tensile Strength Range ksi [1] 180 - 200 Hardness HRC 40-43	Tensile Strength Range ksi [1] 200 - 220 Hardness HRC 43-46
1025	water	700	-	-	-	-	-
1035	water	850	-	-	-	-	-
1035	oil, polymer	700	-	-	-	-	-
1045	water	1050	900	700	-	-	-
1045	oil, polymer	1000	800	-	-	-	-
1065	oil, polymer	1100	950	825	800	775	[13]
1070	oil, polymer	1125	1100	1000	850	800	[13]
1074	oil, polymer	1150	1125	1000	900	800	[13]
1095	oil, polymer	1250	1150	1000	900	800	700
1137	oil, polymer	900	625	-	-	-	-
1137	water	1000	900	800	700	600	-
3140	oil, polymer	1250	1100	975	875	800	-
4037	oil, polymer	1100	1000	925	825	700	-
4037	water	1200	1100	1000	875	725	-
4130 [2]	oil, polymer	1200	1050	925	800	-	-
4130 [2]	water	1250	1100	975	875	700	-
4135 [2]	oil, polymer	1250	1125	1025	900	800	-
4137	oil, polymer	1275	1150	1050	925	825	725
4140 [2]	oil, polymer	1300	1175	1075	950	850	725
4150	oil, polymer	-	1200	1100	975	800	-
4330V, 4330Mod	oil, polymer	-	-	-	-	1000	800 [3]
4335V, 4335Mod	oil, polymer	-	-	-	-	1000	800 [3]
4340 [2]	oil, polymer	-	1200	1100	1025	925	825 [3]
4640	oil, polymer	1200	1100	1000	900	750	-
6150	oil, polymer	-	1200	1100	1000	925	825 [4]
8630 [2]	oil, polymer	1200	1025	925	825	700	-
8630 [2]	water	1200	1025	950	825	700	-
8735 [2]	oil, polymer	1200	1125	1025	800	775	-
8740 [2]	oil, polymer	1275	1175	1075	975	850	725
H-11 [3]	air	-	-	-	-	-	1100
98BV40 Modified	oil, polymer	-	1200	1100	1000	900	800
D6AC [3]	oil, polymer	-	-	-	1200	[5]	[6]
9Ni-4Co-0.20C [3]	oil, polymer		-	-	-	1025 [7]	-
9Ni-4Co-0.30C [3]	oil, polymer		-	-	-		1050 [8]
Nitralloy 135 Mod	oil, polymer		1200 [9]		1100	1000	
Nitralloy EZ	oil, polymer		1200 [10]	1100 [11]			
Nitralloy N	oil, polymer		1200 [12]				
AMS6494, 6495 FND, FNDW	oil, polymer	-	1247	1202	1157	1112	1022
AMS6492, 6493 FDG, FDGW	oil, polymer	-	1148	1022	932	788	572
AMS6481 GKHYW	oil, polymer	-	1238	1184	1157	1112	1040
AMS6497, 6498 GKPW, GKPYW	oil, polymer	-	1256	1220	1184	1157	1112
AMS6547, 6548, 6549 FADH, FADHW, FADHYW	oil, polymer	-	1022	842	707	392	-

NOTES:

[1] Absence of values indicates the respective steel is not recommended for the stated tensile strength range.

[2] See Table 4.

[3] At least two tempering operations required.

[4] Spring temper.

[5] First temper: 1100 °F minimum; second temper: 1115 to 1200 °F.

[6] First temper: 1050 °F minimum; second temper: 1095 to 1145 °F.

[7] 190 ksi minimum tensile strength.

[8] 210 ksi minimum tensile strength.

[9] 135-155 ksi strength range, 30 HRC minimum hardness.

[10] 125-145 ksi strength range, 23 HRC minimum hardness.

[11] 140-160 ksi strength range, 31 HRC minimum hardness.

[12] 130-150 ksi strength range, 28 HRC minimum hardness. Strength level will increase after nitriding due to precipitation hardening at the nitriding temperature. Final strength level is dependent on choice of nitriding temperature. A typical strength level of 190 ksi is developed after nitriding at 975 °F.

[13] In general, 700 to 800 °F to be used for spring temper.

Table 3B - Suggested tempering temperatures (°C)

Material Designation	Quenchant	Tensile Strength Range MPa [1] 621 - 862 Hardness HRB 91-HRC 26	Tensile Strength Range MPa [1] 862 - 1034 Hardness HRC 26-34	Tensile Strength Range MPa [1] 1034 - 1172 Hardness HRC 33-38	Tensile Strength Range MPa [1] 1103 - 1241 Hardness HRC 36-40	Tensile Strength Range MPa [1] 1241 - 1379 Hardness HRC 40-43	Tensile Strength Range MPa [1] 1379 - 1517 Hardness HRC 43-46
1025	water	371	-	-	-	-	-
1035	water	454	-	-	-	-	-
1035	oil, polymer	371	-	-	-	-	-
1045	water	566	482	371	-	-	-
1045	oil, polymer	538	427	-	-	-	-
1065	oil, polymer	593	510	441	427	413	[13]
1070	oil, polymer	607	593	538	454	427	[13]
1074	oil, polymer	621	607	538	482	427	[13]
1095	oil, polymer	677	621	538	482	427	371
1137	oil, polymer	482	329	-	-	-	-
1137	water	538	482	427	371	316	-
3140	oil, polymer	677	593	524	468	427	-
4037	oil, polymer	593	538	496	440	371	-
4037	water	649	593	538	468	385	-
4130 [2]	oil, polymer	649	566	496	427	-	-
4130 [2]	water	677	593	524	468	371	-
4135 [2]	oil, polymer	677	607	552	482	427	-
4137	oil, polymer	691	621	566	496	441	385
4140 [2]	oil, polymer	704	635	579	510	454	385
4150	oil, polymer	-	649	593	524	427	-
4330V, 4330Mod	oil, polymer	-	-	-	-	538	427 [3]
4335V, 4335Mod	oil, polymer	-	-	-	-	538	427 [3]
4340 [2]	oil, polymer	-	649	593	552	496	441 [3]
4640	oil, polymer	649	593	538	482	399	-
6150	oil, polymer	-	649	593	538	496	441 [4]
8630 [2]	oil, polymer	649	552	496	441	371	-
8630 [2]	water	649	552	510	441	371	-
8735 [2]	oil, polymer	649	607	552	427	413	-
8740 [2]	oil, polymer	691	635	579	524	454	385
H-11 [3]	air	-	-	-	-	-	593
98BV40 Modified	oil, polymer	-	649	593	538	482	427
D6AC [3]	oil, polymer	-	-	-	649	[5]	[6]
9Ni-4Co-0.20C [3]	oil, polymer	-	-	-	-	552 [7]	-
9Ni-4Co-0.30C [3]	oil, polymer	-	-	-	-		566 [8]
Nitralloy 135 Mod	oil, polymer		649 [9]		593	593	
Nitralloy EZ	oil, polymer		649 [10]	593 [11]			
Nitralloy N	oil, polymer		649 [12]				
AMS6494, 6495 FND, FNDW	oil, polymer	-	675	650	625	600	550
AMS6492, 6493 FDG, FDGW	oil, polymer	-	620	550	500	420	300
AMS6481 GKHYW	oil, polymer	-	670	640	625	600	560
AMS6497, 6498 GKPW, GKPYW	oil, polymer	-	680	660	640	625	600
AMS6547, 6548, 6549, FADH, FADHW, FADHYW	oil, polymer	-	550	450	375	200	-

NOTES:

[1] Absence of values indicates the respective steel is not recommended for the stated tensile strength range.

[2] See Table 4.

[3] At least two tempering operations required.

[4] Spring temper.

[5] First temper: 593 °C minimum; second temper: 602 to 649 °C.

[6] First temper: 566 °C minimum; second temper: 591 to 618 °C.

[7] 1310 MPa minimum tensile strength.

[8] 1448 MPa minimum tensile strength.

[9] 931-1069 MPa strength range, 30 HRC minimum hardness.

[10] 862-1000 MPa strength range, 23 HRC minimum hardness.

[11] 965-1103 MPa strength range, 31 HRC minimum hardness.

[12] 896-1034 MPa strength range, 28 HRC minimum hardness. Strength level will increase after nitriding due to precipitation hardening at the nitriding temperature. Final strength level is dependent on choice of nitriding temperature. A typical strength level of 190 ksi is developed after nitriding at 524 °C.

[13] In general, use 371 to 427 °C for spring temper.

Table 4A - Suggested approximate tempering temperatures based on as-quenched hardness (°F)

Material Designation	Tensile Strength Range, ksi	As-Quenched Hardness HRC (1) 47 - 49	As-Quenched Hardness HRC (1) 50 - 52	As-Quenched Hardness HRC (1) 53 - 55	As-Quenched hardness HRC (1) 56 - 58	As-Quenched Hardness HRC (1) 59 and Over
4130, 8630, 4135, 8735	125 to 150	1025	1100	1200	-	-
	140 to 160	950	1025	1100	-	-
	150 to 170	875	950	1025	-	-
	170 to 190	800	900	975	-	-
	180 to 200	750	850	925	-	-
4137, 4140, 8740	125 to 150	1100	1150	1200	1250	-
	140 to 160	975	1025	1100	1175	-
	150 to 170	875	950	1025	1100	-
	160 to 180	-	900	975	1050	-
	170 to 190	-	825	925	1000	-
	180 to 200	-	775	875	950	-
	190 to 210	-	725	825	925	-
	200 to 220	-	-	775	875	-
4340	140 to 160	1000	1050	1100	1175	1225
	150 to 170	925	975	1025	1100	1150
	160 to 180	-	900	975	1050	1100
	170 to 190	-	850	925	1000	1050
	180 to 200	-	800	875	950	1000
	190 to 210	-	725	800	900	975
	200 to 220 (2)	-	-	750	850	950

NOTES:
(1) Absence of values indicates the respective steel is not recommended for the stated hardness range.
(2) At least two tempering operations required.

Table 4B - Suggested approximate tempering temperatures based on as-quenched hardness (°C)

Material Designation	Tensile Strength Range, MPa	As-Quenched Hardness HRC (1) 47 - 49	As-Quenched Hardness HRC (1) 50 - 52	As-Quenched Hardness HRC (1) 53 - 55	As-Quenched hardness HRC (1) 56 - 58	As-Quenched Hardness HRC (1) 59 and Over
4130, 8630, 4135, 8735	862 to 1034	552	593	649	-	-
	965 to 1103	510	552	593	-	-
	1034 to 1172	468	510	552	-	-
	1172 to 1310	427	482	524	-	-
	1241 to 1379	399	454	496	-	-
4137, 4140, 8740	862 to 1034	593	621	649	676	-
	965 to 1103	524	552	593	635	-
	1034 to 1172	468	510	552	593	-
	1103 to 1241	-	482	524	566	-
	1172 to 1310	-	441	496	538	-
	1241 to 1379	-	413	468	510	-
	1310 to 1448	-	385	441	496	-
	1379 to 1517	-	-	413	468	-
4340	965 to 1103	538	566	593	635	663
	1034 to 1172	496	524	552	593	621
	1103 to 1241	-	482	524	566	593
	1172 to 1310	-	454	496	538	566
	1241 to 1379	-	427	468	510	538
	1310 to 1448	-	385	427	482	524
	1379 to 1517(2)	-	-	399	454	510

NOTES:
(1) Absence of values indicates the respective steel is not recommended for the stated hardness range.
(2) At least two tempering operations required.

Table 5 - Soak time for annealing, normalizing, and austenitizing

Thickness [1] Inches	Thickness [1] Millimeters	Minimum Soak Time [2], [3], [4], [5] Air or Atmosphere		Minimum Soak Time [2], [3], [4], [5] Salt	
Up to 0.250	Up to 6.35		25 minutes		18 minutes
Over 0.250 to 0.500	Over 6.35 to 12.70		45 minutes		35 minutes
Over 0.500 to 1.000	Over 12.70 to 25.40	1 hour			40 minutes
Over 1.000 to 1.500	Over 25.40 to 38.10	1 hour	15 minutes		45 minutes
Over 1.500 to 2.000	Over 38.10 to 50.80	1 hour	30 minutes		50 minutes
Over 2.000 to 2.500	Over 50.80 to 63.50	1 hour	45 minutes		55 minutes
Over 2.500 to 3.000	Over 63.50 to 76.20	2 hours		1 hour	
Over 3.000 to 3.500	Over 76.20 to 88.90	2 hours	15 minutes	1 hour	5 minutes
Over 3.500 to 4.000	Over 88.90 to 101.60	2 hours	30 minutes	1 hour	10 minutes
Over 4.000 to 4.500	Over 101.60 to 114.30	2 hours	45 minutes	1 hour	15 minutes
Over 4.500 to 5.000	Over 114.30 to 127.00	3 hours		1 hour	20 minutes
Over 5.000 to 8.000	Over 127.00 to 203.20	3 hours	30 minutes	1 hour	40 minutes
Over 8.000	Over 203.20	[6]		[7]	

NOTES:

(1) Thickness is the minimum dimension of the heaviest section of the part.

(2) Soak time commences as specified in 3.4.2 as modified by 3.4.2.1.

(3) In all cases, the parts shall be held for sufficient time to ensure that the center of the most massive area has reached temperature and the necessary transformation and diffusion have taken place.

(4) Maximum soak time at temperature shall not exceed three times the minimum soak time including time additions for copper plating or similar reflective coating.

(5) Longer times may be necessary for parts with complex shapes or parts that do not heat uniformly.

(6) 4 hours plus 30 minutes for every 3 inches (76 mm) or increment of 3 inches (76 mm) greater than 8 inches (203 mm).

(7) 2 hours plus 20 minutes for every 3 inches (76 mm) or increment of 3 inches (76 mm) greater than 8 inches (203 mm).

Table 6A - Maximum hardening size limits for steel parts (inches)

Steel Types	Equivalent Round Dia	Square Thickness	Flat Thickness	Open Tube (Wall)	Closed Tube (Wall)
1025,1035,1045,	0.25	0.20	0.17	0.13	0.10
1065,1070,1074,1095	0.25	0.20	0.17	0.13	0.10
1137	0.25	0.20	0.17	0.13	0.10
3140	0.25	0.20	0.17	0.13	0.10
4037,4130,8630	0.50	0.40	0.33	0.25	0.20
4135,4137, 8735,	0.70	0.56	0.47	0.35	0.28
8740	0.80	0.72	0.53	0.40	0.32
4140,4150	1.00	0.90	0.67	0.50	0.40
4330V,4330Mod	2.50	2.00	1.67	1.25	1.00
4335V,4335Mod	2.50	2.00	1.67	1.25	1.00
4340	2.50	2.00	1.67	1.25	1.00
4340 Martemper	2.33	1.86	1.55	1.16	0.93
4640	0.25	0.20	0.17	0.13	0.10
6150	0.70	0.56	0.47	0.35	0.28
H-11	6.00	4.80	4.00	3.00	2.40
D6AC	5.00	4.00	3.33	2.50	1.43
98BV40 Modified	3.50	2.80	2.33	1.75	1.40
9NI-4Co-0.20	4.00	3.20	2.67	2.00	1.60
9NI-4Co-0.30	4.00	3.20	2.67	2.00	1.60
Nitralloy N	1.00	0.90	0.67	0.50	0.40
Nitralloy EZ	1.00	0.90	0.67	0.50	0.40
Nitralloy 135	1.00	0.90	0.67	0.50	0.40