

HEAT TREATMENT OF CARBON AND LOW-ALLOY STEEL PARTS
Minimum Tensile Strength up to 220,000 psi (1515 MPa)

1. SCOPE: This specification, in conjunction with the general requirements for steel heat treatment covered in AMS 2759, establishes the requirements for heat treatment of carbon and low-alloy steel parts to minimum tensile strengths up to 220,000 psi (1515 MPa). Parts are defined in AMS 2759.
2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Material Specifications and Aerospace Recommended Practices shall apply. The applicable issue of other documents shall be as specified in AMS 2350.
 - 2.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096.
 - 2.1.1 Aerospace Material Specifications:
AMS 2350 - Standards and Test Methods
AMS 2759 - Heat Treatment of Steel Parts, General Requirements
 - 2.1.2 Aerospace Recommended Practices:
ARP 1820 - Chord Method of Evaluating Surface Microstructural Characteristics
 - 2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.
ASTM E384 - Microhardness of Materials
 - 2.3 U.S. Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.
 - 2.3.1 Military Specifications:
MIL-C-14550 - Copper Plating (Electrodeposited)

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3. TECHNICAL REQUIREMENTS:

3.1 Heat Treatment: Shall conform to AMS 2759 and the requirements specified herein.

3.2 Equipment: Shall conform to AMS 2759. Furnace temperature uniformity requirements for annealing, subcritical annealing, normalizing, hardening, straightening, stress relieving, and baking shall be $+25^{\circ}\text{F}$ ($+15^{\circ}\text{C}$), and for tempering shall be $+15^{\circ}\text{F}$ ($+8^{\circ}\text{C}$) except shall be $+10^{\circ}\text{F}$ ($+5^{\circ}\text{C}$) for H-11, D6AC, and 9Ni - 4Co.

3.3 Heating Environment: Parts shall be controlled by type, described in 3.3.1, and heat treated in the class of atmosphere, described in 3.3.2, permitted in Table I for that type when heating above 1300°F (700°C). When heating parts at 1300°F (700°C) or below, class A, B, or C may be used (See 8.2).

3.3.1 Types of Parts: The heat treating processor shall determine the part type.

Type 1: Parts with 0.020 in. (0.50 mm) or more to be machined off all surfaces after heat treatment and parts with as-forged, as-cast, or hot-finished mill surfaces at time of heat treatment with all surfaces to be machined off. Unless informed that all surfaces will have at least 0.020 in. (0.50 mm) machined off, the heat treating processor shall assume all surfaces will not and shall control the part as Type 2, 3, or 4, as applicable.

Type 2: Forgings, castings, sheet, plate, bar, rod, tubing, and extrusions with hot-finished surfaces at time of heat treatment and which will remain on the finished part.

Type 3: Parts with finished machined surfaces or surfaces with less than 0.020 in. (0.50 mm) to be machined off any surface after heat treatment and parts with protective coating on all surfaces.

Type 4: Parts that are partially machined with both unmachined as-forged, as-cast, or hot-finished mill surfaces and finished machined surfaces or machined surfaces with less than 0.020 in. (0.50 mm) to be machined off after heat treatment.

3.3.2 Classes of Atmospheres:

Class A: Argon, hydrogen, helium, nitrogen, nitrogen-hydrogen blends, vacuum, or neutral salt.

Class B: Endothermic, exothermic, or carbon-containing nitrogen-base.

Class C: Air.

TABLE I

Atmospheres

Part Classification (1)	Class A	Class B	Class C
Type 1	Permitted	Permitted	Permitted
Type 2	Permitted	<u>Prohibited</u> (2)	Permitted (3)
Type 3	Permitted	Permitted	<u>Prohibited</u>
Type 4	Permitted	Permitted (3)	<u>Prohibited</u>

(1) See 3.5.1.2

(2) Permitted provided the atmosphere is controlled to produce no carburization or nitriding as described in 3.5.1.

(3) Prohibited if a specific requirement to control the surface carbon on all surfaces is specified.

3.3.3 Atmospheres: Atmosphere furnaces shall be controlled to ensure that surfaces of heat treated parts are within the limits specified in 3.5.1. Salt baths shall be tested in accordance with AMS 2759.

3.3.4 Protective Coatings: A supplemental coating or plating is permitted, when approved by the cognizant engineering organization. Fine grain copper plating, MIL-C-14550, Class 0, may be used without approval but the surface contamination specimens in 3.6.1 shall not be copper plated (See 8.3).

3.4 Procedure:

3.4.1 Preheating: Preheating in the 900° - 1200°F (480° - 650°C) range is recommended before heating parts above 1300°F (700°C) if the parts have previously been heat treated harder than 35 HRC, have abrupt changes of section thickness, have finished machined surfaces, have been welded, have been cold formed or straightened, have holes, or have sharp or only slightly-rounded corners.

3.4.2 Soaking: Heating shall be controlled, as described in AMS 2759, in such a manner that either the heating medium or the part temperature, as applicable, is maintained at the set temperature in Table II, III, or IV for the soak times specified herein. Soaking shall commence when all control, indicating, and recording thermocouples reach the specified set temperature or, if load thermocouples as defined in AMS 2759 are used, when the part temperature reaches the minimum of the furnace uniformity tolerance at the set temperature. In all cases, the parts shall be held for sufficient time to ensure that the center of the most massive section has reached temperature and the necessary transformation and diffusion have taken place.

- 3.4.2.1 Parts coated with copper plate or similar coatings which tend to reflect radiant heat shall have their soak time increased by at least 50%, unless load thermocouples are used.
- 3.4.3 Annealing: Shall be accomplished by heating to the temperature specified in Table II, soaking for the time specified in Table V, and cooling to below the temperature specified in Table II at a rate shown in Table II followed by air cooling to ambient temperature. Isothermal annealing treatments may be used providing equivalent hardness and microstructure are obtained. Isothermal annealing shall be accomplished by heating to the annealing temperature specified in Table II, soaking for the time specified in Table V, molten salt 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 (Stress Relieving): Shall be accomplished prior to hardening by heating in the range 1150° - 1300°F (620° - 700°C), soaking for the time specified in Table V, and cooling to ambient temperature. Steel parts of the 9Ni - 4Co types shall be subcritical annealed as specified in Table II.
- 3.4.5 Normalizing: Shall be accomplished by heating to the temperature specified in Table II, soaking for the time specified in Table V, and cooling in air or atmosphere to ambient temperature.
- 3.4.6 Hardening (Austenitizing and Quenching): Welded parts and brazed parts with a brazing temperature above the normalizing temperature shall be normalized prior to hardening. Hardening shall be accomplished by heating to the austenitizing temperature specified in Table II, soaking for the time shown in Table V, and quenching as specified in Table II.
- 3.4.7 Tempering: Shall be accomplished by heating quenched parts to the temperature required to produce the specified properties. Suggested tempering temperatures for specific tensile strengths for each alloy and quenchant are given in Table III. Alternate tempering temperatures for listed alloys, based on as-quenched hardness, are given in Table IV. The parts shall be held at the set temperature for not less than 2 hr plus 1 hr additional for each inch (25 mm) of thickness or fraction thereof greater than 1 in. (25 mm). Thickness is defined in AMS 2759. When load thermocouples are used, the soaking time shall be not less than 2 hours.
- 3.4.7.1 If hardened parts cannot be tempered within 2 hr of quenching, they shall be snap tempered for 2 hr at a temperature, usually 400°F (200°C), that is lower than the tempering temperature.
- 3.4.8 Straightening: For parts having minimum tensile strength up to 180,000 psi (1240 MPa), straightening may be accomplished cold without stress relieving. When permitted by the cognizant engineering organization, for parts hardened and tempered to minimum tensile strength of 180,000 psi (1240 MPa) and higher, straightening shall be accomplished

at either ambient temperature, during tempering, or by heating to not higher than 50 F (30 C) deg below the tempering temperature. Ambient temperature straightening or 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 temper straightening.

- 3.4.9 Stress Relieving: When required by the cognizant engineering organization, parts shall, after operations which follow hardening and tempering, be stress relieved by heating the parts to 50 F (30 C) deg below the tempering temperature and holding at heat for not less than 1 hr plus 1 hr additional for each inch (25 mm) of thickness or fraction thereof greater than 1 in. (25 mm). When load thermocouples are used, the soaking time shall be not less than 1 hour. Stress relief is prohibited on parts which have been peened or thread- or fillet-rolled after hardening and tempering.
- 3.4.10 Embrittlement Relieving: Baking for hydrogen embrittlement relief shall be accomplished by heating to the temperature specified by the specification controlling the embrittling process (plating, pickling, etc) and holding for the specified time.
- 3.5 Properties: Parts shall conform to the hardness specified by the cognizant engineering organization or to the hardness converted from the required tensile strength in accordance with AMS 2759.
- 3.5.1 Surface Contamination: The protective atmosphere in furnaces for heating parts above 1300°F (700°C), when less than 0.020 in. (0.50 mm) of metal is to be removed from any surface, shall be controlled to prevent carburization or nitriding and to prevent complete decarburization (See 3.5.1.1). Partial decarburization shall not exceed 0.005 in. (0.12 mm). Intergranular oxidation shall not exceed 0.0007 in. (0.018 mm). Rejection criterion for depth of decarburization shall be the microhardness reading at which there is not more than a 20 points Knoop, or equivalent, decrease in hardness from the core hardness. Rejection criterion for carburization and nitriding shall be that the microhardness shall not exceed the core hardness by 20 points Knoop or more, or equivalent, at a depth of 0.002 in. (0.05 mm). Tests shall be in accordance with 3.6.1. The requirements of this paragraph also apply to the cumulative effects of operations such as normalizing followed by austenitizing or austenitizing followed by re-austenitizing (See 3.5.1.3).
- 3.5.1.1 Unless specifically informed that at least 0.020 in. (0.50 mm) will be machined off all surfaces of parts, the heat treating processor shall heat treat the parts as if less than 0.020 in. (0.50 mm) will be removed from some surfaces and, therefore, shall heat treat using controlled atmosphere which will produce parts conforming to the surface contamination requirements.

- 3.5.1.2 Parts that will be machined after heat treatment, but which will have less than 0.020 in. (0.50 mm) of metal removed from any machined surface may be reclassified Type 1, as described in 3.3.1, and need not meet the requirements of 3.5.1 as heat treated, when it is demonstrated by tests on each load that all surface contamination exceeding the requirements of 3.5.1 is removable from all machined surfaces, taking into account distortion after heat treatment.
- 3.5.1.3 It is the responsibility of the heat treating processor to determine whether cumulative heat treating operations at their facility, as described in 3.5.1, have caused excessive surface contamination.
- 3.6 Test Methods: Shall be in accordance with AMS 2759 and as follows:
- 3.6.1 Surface Contamination: Testing shall be performed by the microhardness method in accordance with ASTM E384. Unless otherwise specified, test specimens shall be in the as-quenched condition except that secondary hardening steels, such as H-11, shall be tempered. The presence of total decarburization, carburization, and nitriding and the depth of any intergranular oxidation shall be determined by etching with the appropriate etchant and examining at approximately 250X magnification. The chord method and acceptance limits in ARP 1820 may be used as an alternate and to enhance the intergranular oxidation examination.
4. QUALITY ASSURANCE PROVISIONS: The responsibility for inspection, classification of tests, sampling, approval, entries, records, and reports shall be in accordance with AMS 2759 and as specified in 4.1.
- 4.1 Classification of Tests: The classification of acceptance, periodic, and preproduction tests shall be as specified in AMS 2759 and as specified in 4.1.2 and 4.1.3.
- 4.1.1 Acceptance Tests: Shall be as specified in AMS 2759.
- 4.1.2 Periodic Tests: In addition to the tests specified in AMS 2759, tests to determine conformance to requirements for surface contamination (3.5.1) are classified as periodic tests and 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 0.35% and over 0.35%.
- 4.1.3 Preproduction Tests: In addition to the tests specified in AMS 2759, tests to determine conformance to requirements for surface contamination (3.5.1) are classified as preproduction tests and 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 0.35% and over 0.35%.
5. PREPARATION FOR DELIVERY: See AMS 2759.

6. ACKNOWLEDGMENT: See AMS 2759.
7. REJECTIONS: See AMS 2759.
8. NOTES: Shall be in accordance with AMS 2759 and 8.1 and 8.2.
 - 8.1 Heating below 1400°F (760°C) with Class B atmospheres containing 5% or more of hydrogen (H₂), carbon monoxide (CO), or methane (CH₄), may result in explosion and fire.
 - 8.2 When supplemental plating or coating, such as copper plate, is used, all atmosphere controls and surface contamination tests are still required.
 - 8.3 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.

This specification is under the jurisdiction of AMS Committees "B" and "E".

TABLE II

Annealing, Normalizing, and Austenitizing Temperatures and Quenchants

Material Designation	Annealing (1) Temperature, °F	Normalizing Temperature, °F	Austenitizing Temperature, °F	Hardening Quenchant (2)
1025	1625	1650	1600	water
1035	1600	1650	1550	water or oil
1045	1575	1650	1525	water or oil
1095	1500	1550	1475	oil
1137	1450	1650	1550	oil or water
3140	1500	1650	1500	oil
4037	1550	1650	1550	oil or water
4130	1550	1650	1575	oil or water
4135	1550	1650	1575	oil
4140	1550	1650	1575	oil
4150	1525	1600	1525	oil
4330V	1575	1650	1600	oil
4335V	1550	1650	1600	oil
4340	1550	1650	1500	oil
4640	1550	1650	1525	oil
6150	1550	1650	1600	oil
8630	1550	1650	1575	oil or water
8735	1550	1650	1550	oil
8740	1550	1650	1550	oil
H-11	1600	-	1850	air
98BV40	1550	1600	1550	oil
D6AC (3)	1550	1725	1625 (4)	oil
9Ni-4Co-0.20C	(5)	1650	1525	oil (6)
9Ni-4Co-0.30C	(5)	1700	1550	oil (6)

(1) Cool to below 1000°F, except 4330V and 4340 to below 800°F, and 4640 to below 750°F at a rate not to exceed 200 F deg per hour.

(2) Salt or synthetic quenchants are permitted when approved by the cognizant engineering organization.

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

(4) 1700°F permitted for parts with non-uniform cross-section thickness.

(5) Parts shall be duplex subcritical annealed by heating at 1250°F for 4 hr, air cooling to ambient temperature, reheating to 1150°F for 4 hr, and air cooling to ambient temperature or shall be annealed by heating at 1150°F for 23 - 25 hr and air cooling to ambient temperature.

(6) Within 2 hr after quenching to below 140°F, refrigerate parts at -100°F or lower, hold 60 - 90 min., and air warm to room temperature.

TABLE II (SI)

Annealing, Normalizing, and Austenitizing Temperatures and Quenchants

Material Designation	Annealing (1) Temperature, °C	Normalizing Temperature, °C	Austenitizing Temperature, °C	Hardening Quenchant (2)
1025	885	900	870	water
1035	870	900	845	water or oil
1045	855	845	830	water or oil
1095	815	900	800	oil
1137	785	900	845	oil or water
3140	815	900	815	oil
4037	845	900	845	oil or water
4130	845	900	855	oil or water
4135	845	900	855	oil
4140	845	900	855	oil
4150	830	870	830	oil
4330V	855	900	870	oil
4335V	845	900	870	oil
4340	845	900	815	oil
4640	845	900	830	oil
6150	845	900	870	oil
8630	845	900	855	oil or water
8735	845	900	845	oil
8740	845	900	845	oil
H-11	870	-	1010	air
98BV40	845	870	845	oil
D6AC (3)	845	940	885 (4)	oil
9Ni-4Co-0.20C	(5)	900	830	oil (6)
9Ni-4Co-0.30C	(5)	925	845	oil (6)

- (1) Cool to below 535°C, except 4330V and 4340 to below 425°C, and 4640 to below 400°C at a rate not to exceed 110 C deg per hour.
- (2) Salt or synthetic quenchants are permitted when approved by the cognizant engineering organization.
- (3) Parts shall be in the normalized and tempered condition prior to the initial austenitizing treatment, except that parts only normalized without tempering shall be preheated prior to austenitizing.
- (4) 925°C permitted for parts with non-uniform cross-section thickness.
- (5) Parts shall be duplex subcritical annealed by heating at 675°C for 4 hr, air cooling to ambient temperature, reheating to 620°C for 4 hr, and air cooling to ambient temperature or shall be annealed by heating at 620°C for 23 - 25 hr and air cooling to ambient temperature.
- (6) Within 2 hr after quenching to below 60°C, refrigerate parts at -75°C or lower, hold 60 - 90 min., and air warm to room temperature.

TABLE III

Suggested Tempering Temperatures, °F

Material Designation	Quenchant	Tensile Strength Range, psi (1)					
		90,000 to 125,000	125,000 to 150,000	150,000 to 170,000	160,000 to 180,000	180,000 to 200,000	200,000 to 220,000
1025	water	700	-	-	-	-	-
1035	water	850	-	-	-	-	-
1035	oil	700	-	-	-	-	-
1045	water	1050	900	700	-	-	-
1045	oil	1000	800	-	-	-	-
1095	oil	1250	1150	1000	900	800	700
1137	oil	900	625	-	-	-	-
1137	water	1000	900	800	700	600	-
3140	oil	1250	1100	975	875	800	-
4037	oil	1100	1000	925	825	700	-
4037	water	1200	1100	1000	875	725	-
4130 (2)	oil	1200	1050	925	800	-	-
4130 (2)	water	1250	1100	975	875	700	-
4135 (2)	oil	1250	1125	1025	900	800	-
4140 (2)	oil	1300	1175	1075	950	850	725
4150	oil	-	1200	1100	975	800	-
4330V	oil	-	-	-	-	1000	800 (3)
4335V	oil	-	-	-	-	1000	800 (3)
4340 (2)	oil	-	1200	1100	1025	925	825 (3)
4640	oil	1200	1100	1000	900	750	-
6150	oil	-	1200	1100	1000	925	825
8630 (2)	oil	1200	1025	925	825	700	-
8630 (2)	water	1200	1025	950	825	700	-
8735 (2)	oil	1200	1125	1025	800	775	-
8740 (2)	oil	1275	1175	1075	975	850	725
H-11 (3)	air	-	-	-	1200	1150	1100
98BV40	oil	-	1200	1100	1000	900	800
D6AC (3)	oil	-	-	-	1200	(4)	(5)
9Ni-4Co-0.20C (3)	oil	-	-	-	-	1025 (6)	-
9Ni-4Co-0.30C (3)	oil	-	-	-	-	1050 (7)	-

(1) Absence of values indicates the respective steel is not recommended for the specified tensile strength range.

(2) See Table IV.

(3) At least two tempering operations required.

(4) 1st temper: 1100°F min; 2nd temper: 1115°F - 1200°F.

(5) 1st temper: 1050°F min; 2nd temper: 1095°F - 1145°F.

(6) 190,000 psi min tensile strength.

(7) 210,000 psi min tensile strength.

TABLE III (SI)

Suggested Tempering Temperatures, °C

Material Designation	Quenchant	Tensile Strength Range, MPa (1)					
		620 to 860	860 to 1,035	1,035 to 1,175	1,175 to 1,240	1,240 to 1,380	1,380 to 1,520
1025	water	370	-	-	-	-	-
1035	water	455	-	-	-	-	-
1035	oil	370	-	-	-	-	-
1045	water	565	480	370	-	-	-
1045	oil	540	425	-	-	-	-
1095	oil	675	620	540	480	425	370
1137	oil	480	330	-	-	-	-
1137	water	540	480	425	370	315	-
3140	oil	675	595	525	470	425	-
4037	oil	595	540	495	440	370	-
4037	water	650	595	540	470	385	-
4130 (2)	oil	650	565	495	425	-	-
4130 (2)	water	675	595	525	470	370	-
4135 (2)	oil	675	605	550	480	425	-
4140 (2)	oil	705	635	580	510	455	385
4150	oil	-	650	595	525	425	-
4330V	oil	-	-	-	-	540	425 (3)
4335V	oil	-	-	-	-	540	425 (3)
4340 (2)	oil	-	650	595	550	495	440 (3)
4640	oil	650	595	540	480	400	-
6150	oil	-	650	595	540	495	440
8630 (2)	oil	650	550	495	440	370	-
8630 (2)	water	650	550	510	440	370	-
8735 (2)	oil	650	605	550	425	410	-
8740 (2)	oil	690	635	580	525	455	385
H-11 (3)	air	-	-	-	650	620	595
98BV40	oil	-	650	595	540	480	425
D6AC (3)	oil	-	-	-	650	(4)	(5)
9Ni-4Co-0.20C (3)	oil	-	-	-	-	550 (6)	-
9Ni-4Co-0.30C (3)	oil	-	-	-	-	565 (7)	-

(1) Absence of values indicates the respective steel is not recommended for the specified tensile strength range.

(2) See Table IV.

(3) At least two tempering operations required.

(4) 1st temper: 595°C min; 2nd temper: 600°C - 650°C.

(5) 1st temper: 565°C min; 2nd temper: 590°C - 620°C.

(6) 1310 MPa min tensile strength.

(7) 1450 MPa min tensile strength.