

HEAT TREATMENT OF PRECIPITATION HARDENING
CORROSION RESISTANT AND MARAGING STEEL PARTS

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 precipitation-hardening corrosion-resistant and maraging steel parts. Parts are defined in AMS 2759.

1.1 Application: This specification is applicable to parts made from the following steels:

15-5 PH	PH 13-8 Mo	A-286	Custom 450	Maraging 250
17-4 PH	PH 14-8 Mo	AM-350	Custom 455	Maraging 300
17-7 PH	PH 15-7 Mo	AM-355		

The above designations are trademark or commercial designations and are for alloy recognition only.

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

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AMS 2759/3

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM E3 - Preparation of Metallurgical Specimens
ASTM E8 - Tension Testing of Metallic 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 Federal Specifications:

QQ-P-35 - Passivation Treatments for Corrosion-Resisting Steel

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 shall be as follows:

3.2.1 Furnaces used at temperatures of 1400°F (760°C) and higher and for stress relieving: $\pm 25^{\circ}\text{F}$ ($\pm 15^{\circ}\text{C}$),

3.2.2 Furnaces used at temperatures of 1300°F - 1375°F (705°C - 745°C): $\pm 15^{\circ}\text{F}$ ($\pm 8^{\circ}\text{C}$),

3.2.3 Furnaces used at temperatures below 1300°F (705°C): $\pm 10^{\circ}\text{F}$ ($\pm 5^{\circ}\text{C}$).

3.3 Heating Environment: Parts shall be heat treated in air or protective atmosphere. Acceptable protective atmospheres include argon, helium, hydrogen, neutral salt, and vacuum. Nitrogen and nitrogen-hydrogen blends are permitted only below 1425°F (775°C). Use of nitrogen from dissociated ammonia is prohibited. For scale-free or discoloration-free parts, an air atmosphere and air cooling should be avoided.

3.3.1 Atmospheres: Shall be controlled so as not to react with the parts being heat treated. Furnaces used to heat treat other classes of steel using environments which could contaminate precipitation-hardening or maraging steel parts, such as endothermic, exothermic, carbon-containing nitrogen-base, etc, shall have purge cycles (See 8.2) run and then shall be tested to ensure that the surfaces of parts are not contaminated beyond the limits specified in 3.5.3. Materials which could attack or contaminate metal shall not contact parts. Composition and maintenance of salt baths shall be such as to prevent contamination of the parts. Salt baths shall be tested in accordance with AMS 2759. Heat treating performed in air shall be in a muffle furnace.

- 3.3.2 Protective Coatings: A supplemental coating is permitted to minimize oxidation of finished machined surfaces, when approved by the cognizant engineering organization.
- 3.4 Procedure:
- 3.4.1 Passivation: Parts shall be passivated in accordance with QQ-P-35 before all thermal treatments following forming with dies made from lead, kirksite, or other low-melting temperature materials. Parts shall be passivated in accordance with QQ-P-35 before all thermal treatments above 1350°F (730°C).
- 3.4.2 Spacing: When solution heat treating and austenite conditioning, parts 0.250 in. (6 mm) and under in thickness shall be separated by at least 1 in. (25 mm); thicker parts shall be separated by at least 1 in. (25 mm) plus the part thickness. (Complex parts and parts of large plan form require greater separation.) When aging, parts shall be separated by at least 1 in. (25 mm) except that thin parts may be nested provided thickness of nested stacks does not exceed 1 in. (25 mm) and stacks are at least 1 in. (25 mm) apart. Standard MS type parts and similar industry standard parts may be heat treated nested in baskets.
- 3.4.2.1 Exceptions to the above requirements shall be approved by the cognizant quality assurance or engineering organization, as applicable.
- 3.4.3 Soaking: During solution heat treating and austenite conditioning, soaking shall be for the required time without interruption. 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 I for the soak time shown in Table I or II. 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.
- 3.4.4 Solution Heat Treating (Solution Annealing, Annealing), Austenite Conditioning, and Aging: Shall be accomplished by heating to the temperature specified in Table I, soaking for the time specified in Table I or II, and cooling continuously without interruption as specified in Table I.
- 3.4.4.1 Re-Solution Heat Treating: Only one re-solution heat treat is permitted.

3.4.5 Stress Relieving: When required by the cognizant engineering organization, heat treated parts shall be stress relieved by heating to 100 F (60 C) deg below the aging temperature and holding for at least 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 at least 1 hour. Stress relieving is prohibited on parts which have been peened or thread-rolled after aging.

3.4.6 Carbide Solutioning Treatment (For AM-355): When required, carbide solutioning shall be accomplished by heating to 1900°F (1040°C), soaking for the times listed below for the respective section thickness, water quenching to room temperature, cooling to -100°F (-75°C) or below, holding for 1 - 3 hr, and warming in air to room temperature.

Section Thickness		Soaking Time Hours, minimum
Inches	Millimetres	
Up to 1, excl	Up to 25, excl	1
1 to 3, incl	25 - 75, incl	2
Over 3	Over 75	3

3.4.7 Straightening: When approved by the cognizant engineering organization, straightening shall be accomplished at either ambient temperature, during aging, or by heating to not higher than 50 F (30 C) deg below the aging temperature. Ambient temperature straightening and hot or warm straightening after aging shall be followed by stress relieving. It is permissible to stress relieve after age straightening.

3.5 Properties: Testing shall be as required by AMS 2759 and as specified herein.

3.5.1 Hardness: Precipitation-hardening corrosion-resistant and maraging steel parts shall conform to the hardness specified in Table III for the required condition.

3.5.2 Tensile Properties: When tensile tests are required, results shall conform to the properties specified. When none are specified, they shall conform to those specified by the applicable material specification.

3.5.3 Surface Contamination: When any surface of a part is not to be machined after heat treatment, the atmospheric protection medium in furnaces for heating parts above 1350°F (730°C) shall be controlled to produce no carburization or nitriding (See 3.5.3.1). Intergranular oxidation shall not exceed 0.0007 in. (0.018 mm). Parts heat treated in salt baths shall have no residual salt contamination.

3.5.3.1 Unless informed that the parts will be machined all over, the heat treating processor shall process the parts as though some surfaces will not have metal removed and shall heat treat using controlled atmosphere. Unless specified, controlled atmosphere is not required for parts with only raw material surfaces.

3.6 Test Methods: Shall be in accordance with AMS 2759 and as follows:

3.6.1 Surface Contamination: Testing shall be by metallurgical examination at 500X magnification of etched specimens prepared in accordance with ASTM E3. The chord method in ARP 1820 may be used to enhance this 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 and 4.2.

4.1 Classification of Tests: The classification of acceptance, periodic, and preproduction tests shall be as specified in AMS 2759 and as follows:

4.1.1 Acceptance Tests: In addition to the tests specified in AMS 2759, tests to determine conformance to tensile property (3.5.2) requirements for AM-350 and AM-355 parts and, when specified, for re-resolution heat treated parts are classified as acceptance tests and shall be performed on each lot.

4.1.2 Periodic Tests: In addition to the tests specified in AMS 2759, tests to determine conformance to requirements for surface contamination (3.5.3) are classified as periodic tests. Surface contamination tests shall be performed for each piece of equipment, both monthly and after use of purging atmospheres such as endothermic, exothermic, carbon-containing nitrogen-base, etc, which could contaminate precipitation-hardening or maraging steel parts.

4.1.3 Preproduction Tests: In addition to the tests specified in AMS 2759, tests to determine conformance to requirements for surface contamination (3.5.3) are classified as preproduction tests and shall be performed prior to any production heat treating for each piece of equipment and for each type of atmosphere to be used in each furnace.

4.2 Sampling: Shall be in accordance with AMS 2759 and as follows:

4.2.1 Tensile Testing:

4.2.1.1 For AM-350 and AM-355: At least one tensile specimen conforming to ASTM E8 shall be run with each austenite-conditioning load. It shall be of the same alloy designation as the parts and shall continue with the parts through final aging.

AMS 2759/3

4.2.1.2 For Re-Solution Heat Treated Parts: When specified, at least one tensile specimen conforming to ASTM E8 shall be run with each load. It shall be of the same alloy designation as the parts and shall continue with the parts through final aging.

4.2.2 Surface Contamination Testing: At least one sample shall be run, when required.

5. PREPARATION FOR DELIVERY: See AMS 2759.

6. ACKNOWLEDGMENT: See AMS 2759.

7. REJECTIONS: See AMS 2759.

8. NOTES: See AMS 2759 and as follows:

8.1 Definitions:

8.1.1 Carbide Solutioning Treatment: Heating AM-355 to the solution heat treating temperature followed by rapid cooling and then holding at subzero temperatures to improve the structural uniformity for further heat treatments.

8.1.2 Austenite Conditioning: Heating PH 15-7 Mo, 17-7 PH, PH 14-8 Mo, AM-350, and AM-355 to a temperature below that used for solution heat treating. This conditioning treatment produces a metastable austenite for subsequent transformation upon air cooling or subzero cooling.

8.1.3 Transformation: Cooling to a sufficiently low temperature after austenite conditioning to complete the austenite-to-martensite transformation.

8.2 Purge Cycles: Effective purge cycles can be run to remove contamination from refractory furnace linings using inert gases with small amounts of reducing agents.

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

TABLE I
HEAT TREATING PROCEDURES

Alloy (1)	Final Heat Treat Condition (2)	Solution Heat Treating		Cooling (4)	Austenite Conditioning and Transformation (See 8.1.3) (3) (4)	Aging		
		Set Temperature °F (3)	Set Temperature °C (3)			Set Temperature °F (5)	Set Temperature °C (6)	Time, hr (7)
PH 15-5 PH and 17-4 PH	H 900	1900	1040	Air or oil to below 90°F (30°C) (8)		900	480	1
	H 925					925	495	4
	H 950					950	510	4
	H 1000					1000	540	4
	H 1025					1025	550	4
	H 1050					1050	565	4
	H 1075					1075	580	4
	H 1100					1100	595	4
	H 1150					1150	620	4
	H 1150M (9)					(9)		(9)
PH 17-7 PH and PH 15-7 Mo (10)	RH 950	1925	1050	Air	1750°F (955°C), (3), air cool to ambient and within 1 hr cool below -90°F (-70°C), soak 8 - 9 hours, and air warm to ambient.	950	510	1
	RH 1000					1000	540	1
	RH 1050					1050	565	1
	RH 1075					1075	580	1
	RH 1100					1100	595	1
	TH 950	1925	1050	Air	1400°F (760°C) for 90 min., cool to below 60°F (15°C) within 1 hr, hold below 60°F (15°C) for not less than 30 minutes.	950	510	1 1/2
	TH 1000					1000	540	1 1/2
	TH 1050					1050	565	1 1/2
	TH 1075					1075	580	1 1/2
	TH 1100					1100	595	1 1/2
PH 13-8 Mo	H 950	1700	925	Air or oil to below 60°F (15°C) (8)		950	510	4
	H 1000					1000	540	4
	H 1025					1025	550	4
	H 1050					1050	565	4
	H 1100					1100	595	4
	H 1150					1150	620	4
PH 14-8 Mo (10)	SRH 950	1825	995	Air or oil	1700°F (925°C), (3), air cool to ambient and within 1 hr cool below -90°F (-70°C), soak 8 - 9 hr, and air warm to ambient.	950	510	1
	SRH 1050					1050	565	1
A-286 (11)	Aged	(12)	(12)	Air for sheet and oil for bar		(12)	(12)	(12)
AM-350	SCT 850	1925	1050	Air	1750°F (955°C), (3), air cool, cool below -100°F (-75°C), soak for 3 - 5 hr, and air warm to ambient.	850	455	3
	SCT 950					950	510	3
	SCT 1000					1000	540	3
	SCT 1100					1100	595	3

TABLE I (Continued)

HEAT TREATING PROCEDURES

Alloy (1)	Final Heat Treat Condition (2)	Solution Heat Treating		Cooling (4)	Austenite Conditioning and Transformation (See 8.1.3) (3) (4)	Aging		
		Set Temperature, °F (3)	Set Temperature, °C (3)			Set Temperature, °F (5)(6)(7)	Time, hr (5)(6)(7)	
AM-355	SCT 850	1900	1040	Air or water	1750°F (955°C), (3), water quench, cool below -100°F (-75°C), soak for 3 - 5 hr, and air warm to ambient.	850	455	3
	SCT 1000					1000	540	3
Custom 450	H 900	1900	1040	Air, oil, or water		900	480	4
	H 950					950	510	4
	H 1000					1000	540	4
	H 1050					1050	565	4
	H 1100					1100	595	4
Custom 455	H 900	1525	830	Oil or water		900	480	4
	H 950					950	510	4
Maraging 250 and Maraging 300	H 1000	1500	815	Air		1000	540	4
	Aged					900	480	4 to 6

- (1) These designations are for alloy recognition only.
- (2) See Table IV and V for specified minimum tensile strength conversion to heat treat condition.
- (3) Soak for time listed in Table II.
- (4) Air means air or atmosphere.
- (5) Time, +15, -0 min. for 1 hr ages; +30 min., -0 min. for 1-1/2 hr ages; and +45, -0 min. for 3, 4, and 16 hr ages.
- (6) To get a lower hardness for pretested material, a set temperature up to 10°F (5°C) deg higher than specified may be used.
- (7) An additional 1 - 1-1/2 hr at the specified temperature or an additional 10 - 20°F (5 - 10°C) deg for an additional 1 - 1-1/2 hr after aging may be used to lower the hardness.
- (8) Artificial means may be used to cool below ambient temperature, when necessary to get below 90°F (30°C) or below 60°F (15°C).
- (9) H1150M is an intermediate soft condition that must be re-solution heat treated to obtain a different final condition. To obtain H1150M, solution heat treat, then heat at 1400°F (760°C) for 2 hr plus 1150°F (620°C) for 4 hours.
- (10) For CH 900 age at 900°F (480°C) for 1 hour. Do not re-solution heat treat.
- (11) Procured in two solution heat treated conditions, (1) 1650°F (900°C) for maximum strength and (2) 1750 - 1800°F (955 - 980°C) for maximum high temperature characteristics.
- (12) See Table IV.

TABLE II

SOAK TIMES FOR SOLUTION HEAT TREATING AND AUSTENITE CONDITIONING

Alloy	Form	Minimum Soak Time, minutes (1) (2)	
		Solution Heat Treating	Austenite Conditioning
15-5 PH and 17-4 PH	All except sheet Sheet	30 per in. (25 mm) 3 plus one min. per each 0.010 in. (0.25 mm)	
17-7 PH and PH 15-7 Mo	Sheet All except sheet	3 plus one min. per each 0.010 in. (0.25 mm) 30 per in. (25 mm)	10 plus one min. for each 0.010 in. (0.25 mm) 30 per in. (25 mm)
PH 13-8 Mo	All	30 per in. (25 mm)	
PH 14-8 Mo	Sheet	3 plus one min. per each 0.010 in. (0.25 mm)	60 per in. (25 mm)
A-286	All	60 per in. (25 mm)	
AM-350	Sheet All except sheet	3 plus one min. per each 0.010 in. (0.25 mm) 30 per in. (25 mm)	10 plus one min. for each 0.010 in. (0.25 mm) 30 per in. (25 mm)
AM-355	All	30 per in. (25 mm)	15 per in. (25 mm)
Custom 450 and Custom 455	All	30 per in. (25 mm)	

TABLE II (Continued)

SOAK TIMES FOR SOLUTION HEAT TREATING AND AUSTENITE CONDITIONING

Alloy	Form	Minimum Soak Time, minutes (1) (2)	
		Solution Heat Treating	Austenite Conditioning
Maraging 250 and Maraging 300	All	60 per in. (250 mm)	

- NOTES: (1) Dimension in in. (mm) means in. (mm) or fraction thereof
 (2) Time, +10, -0 minutes

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TABLE III

REQUIRED HARDNESS FOR PRECIPITATION HARDENING
CORROSION RESISTANT STEELS AFTER AGING

Alloy	Form	Condition	Hardness, HRC
15-5 PH and 17-4 PH	All	H 900	40 to 47
		H 925	38 to 45
		H 950	37 to 44
		H 1000	36 to 43
		H 1025	34 to 42
		H 1050	32 to 38
		H 1075	31 to 38
		H 1100	30 to 37
		H 1150	28 to 37
		H 1150M	24 to 30
17-7 PH	All	RH 950	42 to 49
		RH 1000	41 to 46
		RH 1050	40 to 45
		RH 1075	38 to 43
		RH 1100	34 to 40
		TH 950	42 to 48
		TH 1000	40 to 46
		TH 1050	38 to 44
		TH 1075	37 to 42
		TH 1100	34 to 39
		CH 900	46 min
PH 13-8 Mo	All	H 950	45 to 49
		H 1000	43 to 47
		H 1025	41 to 46
		H 1050	40 to 46
		H 1100	34 to 42
		H 1150	30 to 38
		H 1150M	28 to 36
PH 14-8 Mo	Sheet	SRH 950	45 to 51
		SRH 1050	38 to 45

TABLE III (Continued)

REQUIRED HARDNESS FOR PRECIPITATION HARDENING
CORROSION RESISTANT STEELS AFTER AGING

Alloy	Form	Condition	Hardness, HRC
PH 15-7 Mo	Sheet	RH 950	46 to 50
		RH 1000	42 to 46
		RH 1050	39 to 45
		RH 1075	38 to 44
		RH 1100	34 to 42
		TH 1050	40 to 46
		TH 1075	39 to 44
		TH 1100	36 to 41
		CH 900	46 min
A-286	Sheet, Plate	125,000 psi (860 MPa) min	24 to 35
	All	130,000 psi (895 MPa) min	24 to 36
	Sheet, Plate	135,000 psi (930 MPa) min	24 to 37
	Sheet, Plate	140,000 psi (965 MPa) min	24 to 38
	Bar, Forgings	140,000 psi (965 MPa) min	29 to 38
	Bar, Wire	200,000 psi (1380 MPa) min	40 min
AM-350	All	SCT 850	41 to 48
		SCT 950	38 to 45
		SCT 1000	36 to 43
		SCT 1100	35 to 42
AM-355	All	SCT 850	41 to 47
	Plate	SCT 1000	37 to 43
	Bar, Forgings	SCT 1000	38 to 44
Custom 450	All	H 900	39 min
		H 950	37 min
		H 1000	36 min
		H 1050	34 min
		H 1100	30 min
		H 1150	26 min
Custom 455	All	H 900	47 min
		H 950	45 min
		H 1000	44 min