SAE INTERNATIONAL

AEROSPACE MATERIAL SPECIFICATION

AMS2759™/3 REV. F

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Superseding AMS2759/3E

Heat Treatment Precipitation-Hardening Corrosion-Resistant and Maraging Steel Parts

RATIONALE

AMS2759/3F removes the requirement for cooling “within 1 hour” after solution heat treatment from Table 3 for 15-5 PH, 17-4 PH and PH 13-8 Mo, as this has been found to be unnecessary.

1. SCOPE

This specification, in conjunction with the general requirements for steel heat treatment covered in AMS2759, establishes the requirements for heat treatment of precipitation-hardening corrosion- resistant and maraging steel parts. Parts are defined in AMS2759.

1.1 Application

This specification is applicable to parts made from the steels listed in Table 1.

Table 1 - List of 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 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.

AMS2759 Heat Treatment of Steel Parts, General Requirements

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
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ARP1820 Chord Method of Evaluating Surface Microstructural Characteristics

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM A380 Cleaning and Descaling Stainless Steel Parts, Equipment, and Systems

ASTM E3 Preparation of Metallographic Specimens

ASTM E8 Tension Testing of Metallic Materials

ASTM E8M Tension Testing of Metallic Materials (Metric)

3. TECHNICAL REQUIREMENTS

3.1 Heat Treatment

Shall conform to AMS2759 and requirements specified herein.

3.2 Equipment

Shall conform to AMS2759. Furnace temperature uniformity requirements shall be as follows:

3.2.1 Furnaces used at temperatures of 1,400 °F (760 °C) and higher and for stress relieving: ±25 °F (±14 °C).

3.2.2 Furnaces used at temperatures from 1,300 to 1,375 °F (704 to 746 °C): ±15 °F (±8 °C).

3.2.3 Furnaces used at temperatures below 1,300 °F (704 °C): ±10 °F (±6 °C).

3.3 Atmospheres

Shall be controlled so as not to contaminate the parts being heat treated. Furnaces used to heat treat other classes of steel using atmospheres, 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 AMS2759. Heat treating performed in air shall be in the natural atmosphere of a muffle furnace.

3.3.1 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 below 1,425 °F (774 °C). Nitrogen and nitrogen-hydrogen blends are permitted at or above 1,425 °F (774 °C) only if 0.020 inch (0.51 mm) is removed from all surfaces after heat treatment. Nitrogen and nitrogen-hydrogen blends are permitted up to 1,925 °F (1,052 °C) as a backfill quench for vacuum furnaces. Use of nitrogen from dissociated ammonia is prohibited. For scale-free or discoloration-free parts, an air atmosphere and air cooling should be avoided.

3.3.2 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 Acid Cleaning

Parts shall be acid cleaned in accordance with ASTM A380 before thermal treatment following forming with dies made from lead, kirksite, or other low-melting-temperature materials.

3.4.2 Soaking

3.4.2.1 Solution Heat Treating and Austenite Conditioning

Soaking shall be for the required time without interruption. Heating shall be controlled as described in AMS2759, such that either the temperature of the control thermocouple or the load thermocouple, as applicable, is maintained within the set temperature uniformity range for the soak time shown in Tables 2, 3, 4, or 6. Soaking time shall commence when the furnace control thermocouple reaches within 5 °F (3 °C) of the specified set temperature and all other thermocouples reach the minimum of the temperature uniformity range. Alternatively, if a load thermocouple, as defined in AMS2759, is used, soaking time shall commence when its temperature reaches the minimum of the furnace uniformity range.

3.4.2.2 Aging

The control instrument set temperature and the soaking time shall conform to Table 3 except as specified in 3.4.2.2.1. Start of soaking time shall be based on either the furnace control thermocouple (3.4.2.2.1) or a load thermocouple (1) in contact with a part or (2) in contact with a sample representing a part or (3) buried in the load (3.4.2.2.2). Soaking time shall end when parts are removed from the furnace or when parts cool to the minimum of the furnace uniformity range.

3.4.2.2.1 Furnace Control Thermocouple

Soaking time shall start when the temperature indicated by the furnace control instrument (not recorder) recovers to within 5 °F (3 °C) of the set temperature and all other thermocouples reach the minimum of the temperature uniformity range. It is permissible to increase the soaking time by up to 50% of the time specified in Table 3 to compensate for the lag in part temperature due to specific characteristics of the parts or the load, for example part thickness, load weight, shielding or interference with circulation due to part configuration.

3.4.2.2.2 Load Thermocouple

Soaking time shall start when the load thermocouple temperature reaches the minimum of the temperature uniformity range.

3.4.3 Solution Heat Treating (Solution Annealing, Annealing), Austenite Conditioning, and Aging (Precipitation Heat Treating)

Shall be accomplished by heating to the temperature specified in Tables 3 or 6, soaking for the time specified in Tables 3, 4, or 6, and cooling continuously without interruption as specified in Tables 3, 4, and 6.

3.4.3.1 Re-solution Heat Treating

Only one re-solution heat treatment is permitted.

3.4.4 Stress Relieving

When required by the cognizant engineering organization, heat treated parts shall be stress relieved by heating to 100 °F (56 °C) below the aging temperature and soaking for at least 1 hour plus 1 hour additional for each inch (25 mm) of thickness or fraction thereof greater than 1 inch (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.

3.4.5 Carbide Solutioning Treatment (For AM-355)

When required, carbide solutioning shall be accomplished by heating to 1,900 °F (1,038 °C), soaking for the times shown in Table 2 for the respective section thickness, water quenching to room temperature, cooling to -90 °F (-68 °C) or below, holding for 1 to 3 hours, and warming in air to room temperature.

Table 2 - Time for carbide solution treatment

Section Thickness Inches	Section Thickness Millimeters	Soaking Time Hours, minimum
Up to1, excl	Up to 25, excl	1
1 to 3, incl	25 to 76, incl	2
Over 3	Over 76	3

3.4.6 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 (28 °C) 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 straightening during aging.

3.5 Properties

Testing shall be as required by AMS2759 and as specified herein.

3.5.1 Hardness

Precipitation-hardening corrosion-resistant and maraging steel parts shall conform to the hardness shown in Table 5 for the required condition.

3.5.2 Tensile Properties

When tensile tests are required, results shall conform to the specified values. When tensile properties are not 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 protective atmosphere or backfill medium in furnaces for heating parts above 1,350 °F (732 °C) shall be controlled to not produce carburization or nitriding (see 3.5.3.1) and intergranular oxidation shall not exceed 0.0007 inch (0.018 mm). Parts heat treated in salt baths shall be free of residual salts.

3.5.3.1 Unless specifically informed that the parts will be machined all over, the heat treating processor shall process the parts as though some surfaces will not have subsequent metal removal and, therefore, shall heat treat above 1,350 °F (732 °C) with controlled atmosphere which will conform to the surface contamination requirements. Unless specified, controlled atmosphere is not required for parts with only raw material surfaces, except those made from sheet or strip.

3.5.3.2 Furnaces used exclusively to heat treat parts which will have all contamination removed shall not require testing.

3.6 Test Methods

Shall be in accordance with AMS2759 and as follows:

3.6.1 Surface Contamination

Testing shall be by metallurgical examination at approximately 500X magnification of etched specimens prepared in accordance with ASTM E3. The chord method in ARP1820 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 AMS2759 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 AMS2759 and as specified in 4.1.1 thru 4.1.3.

4.1.1 Acceptance Tests

Tensile property requirements (3.5.2) for the following are acceptance tests and shall be performed on each lot: AM-350 and AM-355 parts; 17-7PH and PH15-7Mo parts heat treated to the RH Condition; 15-5PH and 17-4PH parts aged from 1,100 °F (593 °C) to 1,150 °F (621 °C); when specified, for re-solution heat treated parts.

4.1.2 Periodic Tests

Surface contamination (3.5.3) is a periodic test and shall be performed for each piece of equipment after the purging of atmospheres whenever the equipment has been used previously to heat treat using atmospheres, such as endothermic, exothermic, carbon-containing nitrogen-base, etc., which could contaminate precipitation-hardening or maraging steel parts.

4.1.3 Preproduction Tests

Surface contamination (3.5.3) is a preproduction test 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 and Testing

Shall be in accordance with AMS2759 and as follows:

4.2.1 Tensile Testing

4.2.1.1 For AM-350 and AM-355

One or more tensile specimens conforming to ASTM E8 or ASTM E8M shall be processed 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.

4.2.1.2 For 17-4PH and 15-5PH aged from 1,100 °F (593 °C) to 1,150 °F (621 °C)

One or more tensile specimens conforming to ASTM E8 or ASTM E8M shall be processed with each aging load. It shall be of the same alloy designation as the parts.

4.2.1.3 For 17-7PH and PH15-7Mo to the RH Condition

One or more tensile specimen conforming to ASTM E8 or ASTM E8M shall be processed 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.

4.2.1.4 For Re-solution Heat Treated Parts

When specified, one or more tensile specimens conforming to ASTM E8 or ASTM E8M shall be processed 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

One or more samples shall be processed.

5. PREPARATION FOR DELIVERY

In accordance with AMS2759.

6. ACKNOWLEDGMENT

In accordance with AMS2759.

7. REJECTIONS

In accordance with AMS2759.

8. NOTES

Shall be in accordance with 8.1, 8.2, 8.3, and AMS2759.

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 Purge Cycles

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

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

8.3.1 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.

8.3.2 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.

8.3.3 Transformation

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

8.3.4 Set temperature uniformity range: The temperature range derived from applying the required temperature uniformity tolerance for the specific process to the specified set temperature. For example, if the specified set temperature is 900 °F and the required temperature uniformity tolerance is ±10 °F, then the set temperature uniformity range is 890 to 910 °F.

8.4 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.

Table 3 - Heat treating procedures

Alloy (1)	Final Heat Treat Condition (2)	Solution Heat Treating Set Temp °F (3)	Solution Heat Treating Set Temp °C (3)	Solution Heat Treating Cooling (4)	Austenite Conditioning and Transformation (see 8.3.2 and 8.3.3) (3) (4)	Aging Set Temp °F (5) (6)	Aging Set Temp °C (5) (6)	Aging Time, Hours (5) (7)
15-5 PH and 17-4 PH	H 900	1,900	1,038	Air cool or faster to below 90 °F (32 °C) (9)	None	900	482	1 (8)
	H 925					925	496	4 (8)
	H 950					950	510	4
	H 1000					1,000	538	4
	H 1025					1,025	552	4
	H 1050					1,050	566	4
	H 1075					1,075	579	4
	H 1100					1,100	593	4
	H 1150					1,150	621	4
	H 1150 M (10)					(10)	(10)	(10)
17-7 PH and PH 15-7 Mo	RH 950	1,925	1,052	Air cool or faster	1,750 °F (954 °C), air cool to ambient and within 1 hour cool below -90 °F (-68 °C), soak 8 to 9 hours, and air warm to ambient. (Results in Cond. R)	950	510	1
	RH 1000					1,000	538	1
	RH 1050					1,050	566	1
	RH 1075					1,075	579	1
	RH 1100					1,100	593	1
	TH 950	1,925	1,052	Air cool or faster	1,400 °F (760 °C) for 90 minutes, cool to below 60 °F (16 °C) within 1 hour, hold below 60 °F (16 °C) for not less than 30 minutes. (Results in Cond. T)	950	510	1 1/2
	TH 1000					1,000	538	1 1/2
	TH 1050					1,050	566	1 1/2
	TH 1075					1,075	579	1 1/2
	TH 1100					1,100	593	1 1/2
	CH 900 (11)	None	None	None	None	900	482	1
PH 13-8 Mo	H 950	1,700	927	Air cool or faster to below 60 °F (16 °C) (9)	None	950	510	4
	H 1000					1,000	538	4
	H 1025					1,025	552	4
	H 1050					1,050	566	4
	H 1100					1,100	593	4
	H 1150					1,150	621	4
	H 1150M (10)					(10)	(10)	(10)
PH 14-8 Mo	SRH 950	1,825	996	Air cool or faster	1,700 °F (927 °C), air cool to ambient and within 1 hour cool below -90 °F (-68 °C), soak 8 to 9 hours, and air warm to ambient.	950	510	1
	SRH 1050					1,050	566	1
	CH 900 (11)	None	None	None	None	900	482	1
A-286 (12)	Aged	(13)	(13)	Sheet: air cool or faster Other forms: water, oil or polymer (15)	None	(13)	(13)	(13)
AM-350	SCT 850	1,925	1,052	Air cool or faster	1,750 °F (954 °C), air cool, cool below -90 °F (-68 °C) within 1 hour, soak for 3 to 5 hours, and air warm to ambient.	850	454	3
	SCT 950					950	510	3
	SCT 1000					1,000	538	3
	SCT 1100					1,100	593	3
AM-355	SCT 850	1,900	1,038	Air cool or faster	1,750 °F (954 °C), water quench, cool below -90 °F (-68 °C) within 1 hour, soak for 3 to 5 hours, and air warm to ambient.	850	454	3
	SCT 1000					1,000	538	3

Table 3 - Heat treating procedures (continued)

Alloy (1)	Final Heat Treat Condition (2)	Solution Heat Treating Set Temp °F (3)	Solution Heat Treating Set Temp °C (3)	Solution Heat Treating Cooling (4)	Austenite Conditioning and Transformation (see 8.3.2 and 8.3.3) (3) (4)	Aging Set Temp °F (5) (6)	Aging Set Temp °C (5) (6)	Aging Time, Hours (5) (7)
Custom 450	H 900	1,900	1,038	Air cool or faster	None	900	482	4
	H 950					950	510	4
	H 1000					1,000	538	4
	H 1025					1,025	552	4
	H 1050					1,050	566	4
	H 1100					1,100	593	4
	H 1150					1,150	621	4
Custom 455 (14)	H 900	1,525	829	Oil, polymer, or water	None	900	482	4
	H 950					950	510	4
	H 1000					1,000	538	4
	CH 850 (14)	None	None	None	None	850	454	1/2
Maraging 250 and Maraging 300	Aged	1,500	816	Air cool or faster	None	900	482	4 to 6

NOTES:
1. These designations are for alloy recognition only.
2. See Tables 6 and 7 for specified minimum tensile strength conversion to heat treat condition.
3. Soak for time listed in Table 4, unless otherwise indicated.
4. Air means air or atmosphere.
5. When part hardness after aging exceeds the required maximum, additional aging shall be performed to reduce the hardness. The set temperature for the additional aging shall be that in Table 3 or up to 20 °F (11 °C) higher. The soaking time for the additional aging shall be not more than 90 minutes except it is permissible to add lag time compensation as specified in 3.4.2.2.1.
6. To produce a lower hardness for pretested material, a set temperature up to 10 °F (6 °C) higher than specified may be used.
7. Except for maraging grades, tolerance for soaking time shall be +10, -0 minutes for 30 minute ages; +15, -0 minutes for 1 hour ages; +30 minutes, -0 minutes for longer ages.
8. 17-4 PH and 15-5 PH castings, H 900, and H 925 time shall be 1-1/2 hours.
9. Artificial means may be used to cool below ambient temperature, when necessary, to get below 90 °F (32 °C) or below 60 °F (16 °C).
10. H 1150M is an intermediate soft condition that must be re-solution heat treated to obtain a different final condition. To obtain H 1150M, solution heat treat, then heat at 1,400 °F (760 °C) for 2 to 2-1/2 hours, air cool below 90 °F (32 °C) plus 1,150 °F (621 °C) for 4 hours.
11. For CH 900 do not re-solution heat treat.
12. Procured in two solution heat treated conditions, (1) 1,650 °F (899 °C) for maximum strength and (2) 1,750 to 1,800 °F (954 to 982 °C) for maximum high temperature characteristics.
13. See Table 6.
14. For CH 850 do not re-solution heat treat.
15. Gas backfill quenching of forms other than sheet is acceptable provided mechanical properties are tested after precipitation hardening and results conform to requirements.

Table 4 - Soak times for solution heat treating and austenite conditioning

Alloy	Form	Minimum Soak Time Minutes (1) (2) (3) Solution Heat Treating	Minimum Soak Time Minutes (1) (2) (3) Austenite Conditioning
15-5 PH and 17-4 PH	Sheet	3 plus one minute for each 0.010 inch (0.25 mm)	
	All except sheet	30 for inch (25 mm)	
17-7 PH and PH 15-7 Mo	Sheet	3 plus one minute for each 0.010 inch (0.25 mm)	10 plus one minute for each 0.010 inch (0.25 mm)
	All except sheet	30 for inch (25 mm)	30 per inch (25 mm)
PH 13-8 Mo	All	30 for inch (25 mm)	
PH 14-8 Mo	Sheet	3 plus one minute for each 0.010 inch (0.25 mm)	60 per inch (25 mm)
A-286	All	60 for inch (25 mm)	
AM-350	Sheet	3 plus one minute for each 0.010 inch (0.25 mm)	10 plus one minute for each 0.010 inch (0.25 mm)
	All except sheet	30 for inch (25 mm)	30 per inch (25 mm)
AM-355	Sheet	3 plus one minute for each 0.010 inch (0.25 mm)	10 plus one minute for each 0.010 inch (0.25 mm)
	All except sheet	30 for inch (25 mm)	15 per inch (25 mm)
Custom 450 and Custom 455	All	30 for inch (25 mm)	
Maraging 250 and Maraging 300	All	60 for inch (25 mm)	

NOTES:
1. Dimension in inch (mm) means inch (mm) or fraction thereof.
2. Time: +10, -0 minutes.
3. 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.

Table 5 - Required hardness for precipitation-hardening corrosion-resistant steels after aging

Alloy	Form	Condition	Hardness HRC
15-5 PH	All	H 900	40 to 47
and		H 925	38 to 45
17-4 PH		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 48
		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
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 ksi (862 MPa) min	24 to 35
	All	130 ksi (896 MPa) min	24 to 36
	Sheet, Plate	135 ksi (931 MPa) min	24 to 37
	Sheet, Plate	140 ksi (965 MPa) min	24 to 38
	Bar, Forgings	140 ksi (965 MPa) min	29 to 38
	Bar, Wire	200 ksi (1379 MPa) min	40 min

Table 5 - Required hardness for precipitation-hardening corrosion-resistant steels after aging (continued)

Alloy	Form	Condition	Hardness HRC
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 1025	35 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
Maraging 250	All	Aged	49 to 52
Maraging 300	All	Aged	52 to 56