Process Specification for the Heat Treatment of Aluminum Alloys

Engineering Directorate

Structural Engineering Division

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REVISIONS		
VERSION	CHANGES	DATE
Baseline	Original version	5/96
A	Expanded sec. 3.0, furnace chart info., tensile requirements, conductivity measurements	5/27/98
B	Changed Training Requirements, Changed Tensile Test Requirements from ASTM E8 to ASTM B557, Require Tensile Test Coupons for Solution Heat Treatment	7/21/99
C	Modified Training Requirements, Labeling Tensile Bars & Stock	2/24/00
D	Included Information on Postweld Heat Treatment, Reduced Labeling Tensile Bars & Stock Requirements, Additional Word Definitions	8/24/00
E	Update document due to reorganization from EM2 to ES4	1/20/04
F	Reviewed for accuracy and updated author.	10/04/06
G	Clarified the Usage statement	8/10/09
H	Verify current condition of raw stock material; added Table 1 and Table 2; subdivided PROCESS VERIFICATION section; added statements to section 8.0.1 on eutectic melting and hydrogen blistering; added AMS 2772 and ASTM E1004 under REFERENCES; replaced JSC 8500 with JPR 8500.4 under REFERENCES; updated and added definitions to section 10.0; other grammatical changes.	10/2011

1.0 SCOPE

This process specification establishes the engineering requirements for the heat treatment of aluminum alloys.

2.0 APPLICABILITY

This specification shall be applicable whenever the heat treatment of aluminum alloys is invoked per section 3.0, “Usage”. Heat treatment of aluminum alloys may be performed on raw stock material (i.e: sheet, plate, wire, rod and bar, tubing, forgings and extrusions) or on parts produced from raw material.

3.0 USAGE

The material to be heat treated shall be listed on the drawing, in the heat treat condition in which the material is to be procured; the procurement specification shall be listed alongside the material to be heat treated. Availability of product forms and tempers may be obtained from a manufacturing production controller or from an ES4 materials engineer.

This process specification shall be called out on the engineering drawing by using an appropriate drawing note. The specific heat treat process or combination of processes shall be noted along with the final temper. For example:

SOLUTION HEAT TREAT AND AGE HARDEN TO THE T6 TEMPER PER NASA/JSC PRC-2002.

OR

AGE HARDEN TO T7351 TEMPER PER NASA/JSC PRC-2002.

3.1 PROCESS SEQUENCE

All parts shall be heat treated before final machining, unless otherwise specified on the engineering drawing. Solution heat treatment of aluminum alloys is often followed by quenching from temperatures above 900°F into water, which can cause considerable distortion and high residual stresses. **Designers should consult with an ES4 materials engineer when considering designs that require solution heat treatment and quenching of aluminum alloys.**

3.1.1 Post Weld Stress Relieving

Most post weld heat treat operations, if required, on aluminum alloys are generally:

a) solution heat treatment + quenching
b) solution heat treatment + quenching + aging
c) aging

A qualified welding procedure for the specific application needs to be reviewed before making the post weld heat treat note. For example:

AFTER WELDING, SOLUTION HEAT TREAT AND AGE HARDEN TO THE T6 TEMPER PER NASA/JSC PRC-2002.

3.1.2 Forming

If an aluminum alloy is to be formed, the age hardening process should occur after forming and should be noted on the drawing. For example:

AGE HARDEN TO T73 TEMPER PER NASA/JSC PRC-2002 AFTER FORMING.

4.0 REFERENCES

All documents listed are assumed to be the current revision unless a specific revision is listed.

AMS 2770	Society of Automotive Engineers Aerospace Material Specification, *Heat Treatment of Wrought Aluminum Alloy Parts*
AMS 2772	Society of Automotive Engineers Aerospace Material Specification, *Heat Treatment of Aluminum Alloy Raw Materials*
AMS 2658	Society of Automotive Engineers Aerospace Material Specification, *Hardness and Conductivity Inspection of Wrought Aluminum Alloy Parts*

ASTM E18	American Society for Testing and Materials Specification, *Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*
ASTM E1004	American Society for Testing and Materials Specification, *Standard Test Methods for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*
ASTM B557	American Society for Testing and Materials Specification, *Standard Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*
MMPDS	Handbook, *Metallic Materials Properties Development and Standardization*
TI-2000-01	Training Instruction: Training for Heat Treat Personnel
SAE ARP 1962	Training and Approval of Heat-Treating Personnel

The following references were used in developing this process specification:

SOP-007.1	Preparation and Revision of Process Specifications
JPR 8500.4	Engineering Drawing System Requirements

5.0 MATERIALS REQUIREMENTS

Current heat treat condition shall be verified (i.e: MTRs) before performing any subsequent heat treatment on raw stock material. Subsequent heat treatment shall be performed per AMS 2772.

Material requirements for parts shall be as specified in AMS 2770.

6.0 PROCESS REQUIREMENTS

6.0.1 Raw Stock Aluminum Alloy Material

All heat treatment of raw aluminum alloy shall comply with the process requirements in AMS 2772 and the engineering drawing requirements.

Specific heat treating times and temperatures are provided in various tables in AMS 2772. Table 1 provides a list of these heat treating tables.

Table 1: List of Tables with Heat Treating Times and Temperatures Per AMS 2772

Table	Name
1	Solution Heat Treating Temperatures
2	Recommended Minimum Soaking Time For Solution Heat Treatment of Wrought Products
3	Maximum Quench Delay (For Immersion Quenching)
4	Recommended Aging Treatments
5A	Mandatory Solution Heat Treatment Set Temperatures For Response-To-Heat-Treatment Tests
5B	Mandatory Solution Heat Treatment Set Temperatures And Times For Response-To-Heat-Treatment Tests
6A	Recommended Solution Heat Treatment Set Temperatures For Response-To-Heat-Treatment Tests
6B	Recommended Aging Set Temperatures And Times For Response-To-Heat-Treatment Tests

Tools and equipment shall be as specified in SAE AMS 2772. Safety precautions and warning notes shall be as specified in SAE AMS 2772.

6.0.2 Aluminum Alloy Parts

All heat treatment of aluminum alloy parts shall comply with the process requirements in AMS 2770 and the engineering drawing requirements.

Specific heat treating times and temperatures are provided in various tables in AMS 2770. Table 2 provides a list of these heat treating tables.

Table 2: List of Tables with Heat Treating Times and Temperatures Per AMS 2770

Table	Name
1	Quenching Temperature for Forgings
2	Solution Heat Treating Temperatures
3	Solution Heat Treating Soaking Times
4	Limits for Quenching in Polymer Solutions

5	Maximum Quench Delay Times
6	Refrigeration
7	Aging Treatments
8	Annealing

Most aging temperatures in Table 7 of AMS 2770 are labeled as mandatory (M). The preferred (P) aging temperature shall be used over the alternate (A) aging temperature when the aging temperature is not labeled mandatory.

Tools and equipment shall be as specified in SAE AMS 2770. Safety precautions and warning notes shall be as specified in SAE AMS 2770.

7.0 PROCESS QUALIFICATION

Not required. However, work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable products that comply with this specification.

8.0 PROCESS VERIFICATION

8.0.1 Verification of Heat Treat Cycles

Verification of furnace temperatures shall be accomplished by recording the furnace temperatures on strip charts or other suitable hard copy recordings. Tight temperature tolerances must be enforced in furnaces that are used to solution heat treat in an effort to avoid eutectic melting. Hydrogen may be absorbed during eutectic melting resulting in hydrogen blistering as observed in Figure 1. ES4 Materials and Processes must be notified as soon as possible if hydrogen blisters are detected. Furnace charts for heat treatment shall be maintained with the hardware's work order router package.

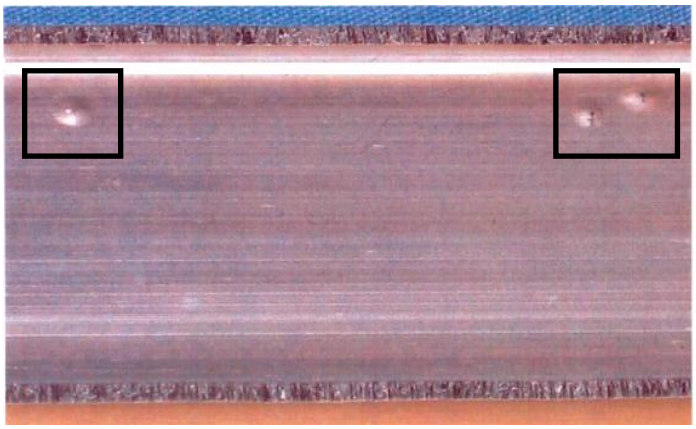

Figure 1: Hydrogen Blisters on Al 6061T6511.

8.0.2 Heat Treat Verification by Hardness and Conductivity Test

Verification of aluminum heat treat is generally achieved by measuring hardness and conductivity. Hardness tests shall be performed per ASTM E18. Conductivity tests shall be performed per ASTM E1004.

8.0.2.1 Notations Related to Hardness and Conductivity Tests

Hardness and conductivity tests will be performed on the raw stock material or the semi-finished part unless otherwise specified on the engineering drawing. Hardness impressions will be machined away during subsequent machining for most parts. When hardness impressions must be made on the finished part, a test location shall be chosen by the designer and the materials engineer that will not be detrimental to the function of the finished part. Notes must be included on the engineering drawing, such as:

HARDNESS AND CONDUCTIVITY TESTS SHALL BE PERFORMED ON FINISHED PART IN LOCATION SPECIFIED.

Hardness and conductivity tests may be performed on sample parts instead of finished parts. Sample parts shall be sketched and/or described on the engineering drawing. They may have a simplified contour and may use nominal dimensioning. Sample parts shall be made from the same lot of raw stock material and processed before heat treatment in an identical manner as the finished parts.

When solution heat treatment is followed by quenching, the sample parts must be of similar cross section as the finished parts or shall be parted from the same lot of raw stock material that will be used for finished parts post heat treatment. If finished parts have to be processed in more than one batch and sample parts are needed, each batch must have its own set of labeled sample parts.

When hardness and conductivity tests are to be performed on a sample part, the following notation should be included on the engineering drawing:

HARDNESS AND CONDUCTIVITY TESTS SHALL BE PERFORMED ON SAMPLE PART. SAMPLE PART SHALL CONSIST OF ONE 1" LENGTH OF THE SAME MATERIAL LOT USED FOR FINISHED PARTS.

OR

HARDNESS AND CONDUCTIVITY TESTS SHALL BE PERFORMED ON 2" PROLONGATION OF RAW STOCK MATERIAL THAT IS PARTED AFTER HEAT TREATMENT.

8.0.2.2 Hardness and Conductivity Test Results

Hardness and conductivity measurements must meet the acceptance values listed in AMS 2658.

8.0.3 Heat Treat Verification By Tensile Test

Tensile tests are required when the heat treating process includes solution heat treatment. Tensile tests shall be performed according to ASTM B557 by either the JSC Structures Test Laboratory, the Receiving Inspection, and Test Facility (RITF), or an accredited mechanical testing laboratory. Tensile test coupons shall be machined according to ASTM B557, using full-sized coupons whenever possible.

8.0.3.1 Notations Related to Tensile Tests

Sample parts for tensile coupons shall be machined from the same lot of raw stock material and processed before heat treatment in an identical manner as the finished parts. The number of coupons, grain direction (when applicable), and any special acceptance criteria (i.e: tensile strength, % elongation, etc) shall be noted on the engineering drawing when tensile testing is required. For example:

TENSILE TESTING IS REQUIRED AND SHALL BE PERFORMED ON SAMPLE PART(S). SAMPLE PARTS SHALL CONSIST OF THREE 6" LENGTHS OF THE SAME LOT OF MATERIAL USED FOR FINISHED PARTS.

8.0.3.2 Labeling of Tensile Coupons

Tensile bars or tensile coupons shall be individually labeled. Label information shall always include material lot certification #. If the tensile bars or tensile coupons are made prior to heat treating, the tensile bars or tensile coupons shall be labeled using austenitic stainless tags and austenitic stainless wire. If the tensile bars or tensile coupons are made after heat treating, cotton string and paper tags may be used instead of austenitic stainless tags and wire. Paper tags shall include the material type, the material lot certification #, and the work order router number.

8.0.3.3 Tensile Test Results

Tensile test results for aluminum alloys shall meet the minimum values listed in MMPDS. Tensile test results may indicate the presence of eutectic melting, which can be observed by a metallographic analysis.

8.0.4 Miscellaneous

Hardness, conductivity, and tensile tests are not required post weld stress relieving operations, except for rare exceptions.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

All heat treatment of aluminum alloys used on flight hardware shall be performed by qualified operators who have been certified according to the requirements in TI-2000-01, Training for Heat Treat Personnel. For vendors, a training program consistent with the recommended practices in SAE ARP 1962 shall be required.

10.0 DEFINITIONS

Solution Heat Treatment	heating an alloy to a suitable temperature and holding at temperature long enough to cause one or more hardening constituents to enter into solid solution
Quench	cooling an alloy, rapidly enough to hold hardening constituents in solution
Age Harden	precipitation of hardening constituents either at room temperature (natural aging) or elevated temperature (artificial aging)
Eutectic Melting	when solution heat treating, raising the temperature to or above the melting temperature of the hardening constituents in an aluminum alloy; reduces ductility, toughness, and fatigue strength
Hydrogen Blistering	absorption of hydrogen in liquated aluminum generally caused by exceeding the solidus temperature during solution heat treatment; precipitation of hydrogen within the aluminum alloy completely forces the grains apart forming blisters or fissures
Stress Relieve	A thermal cycle to relieve residual stresses.