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| <b>AEROSPACE<br/>MATERIAL SPECIFICATION</b>   | <b>AMS5960™</b> | <b>REV. B</b> |
|   | Issued          | 2013-08       |
|   | Revised         | 2024-06       |
| Superseding AMS5960A  |                 |               |
| Nickel Alloy, Corrosion- and Heat-Resistant Sheet, Strip, and Foil<br>Ni - 18Cr - 2.8Mo - 5.5Cb (Nb) - 0.70Ti - 1.50Al - 10Fe - 9Co - 1W (Alloy 718+)<br>Vacuum Induction Melted and Consumable Electrode Remelted,<br>Solution Heat Treated<br>(Composition similar to UNS N07818) |                 |               |

### RATIONALE

AMS5960B is the result of a Five-Year Review and update of the specification. The revision updates the Title to add the common name, updates composition testing and reporting (see 3.1 and 3.1.1), revises finish requirements (see 3.3.1), adds strain rate to tensile testing requirements (see 3.5.2.1.1.1), clarifies bend testing (see 3.5.1.3), adds pyrometry controls (see 3.5.2), clarifies hardness test conversions (see 8.2), and updates the requirements for exceptions to this specification (see 3.5.3, 4.4.1, and 8.5).

#### 1. SCOPE

##### 1.1 Form

This specification covers a corrosion- and heat-resistant nickel alloy in the form of sheet, strip, and foil 0.1874 inch (4.76 mm) and under in nominal thickness.

##### 1.2 Application

These products have been used typically for parts requiring resistance to creep and stress-rupture up to 1400 °F (760 °C) and oxidation resistance up to 1800 °F (982 °C), particularly those parts which are formed or welded and then precipitation heat treated to develop desired properties, but usage is not limited to such applications.

#### 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), or [www.sae.org](http://www.sae.org).

AMS2262      Tolerances, Nickel, Nickel Alloy, and Cobalt Alloy Sheet, Strip, and Plate

AMS2269      Chemical Check Analysis Limits, Nickel, Nickel Alloys, and Cobalt Alloys

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|         |  |
|---------|--|
| AMS2371 | Quality Assurance Sampling and Testing, Corrosion and Heat-Resistant Steels and Alloys, Wrought Products and Forging Stock           |
| AMS2750 | Pyrometry  |
| AMS2807 | Identification, Carbon and Low-Alloy Steels, Corrosion and Heat-Resistant Steels and Alloys Sheet, Strip, Plate, and Aircraft Tubing |
| AS7766  | Terms Used in Aerospace Metals Specifications  |

## 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, or [www.astm.org](http://www.astm.org).

ASTM A480/A480M Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip

ASTM E3 Preparation of Metallographic Specimens

ASTM E8/E8M Tension Testing of Metallic Materials

ASTM E18 Rockwell Hardness of Metallic Materials

ASTM E21 Elevated Temperature Tension Tests of Metallic Materials

ASTM E112 Determining Average Grain Size

ASTM E139 Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials

ASTM E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

ASTM E290 Bend Testing of Material for Ductility

ASTM E384 Microindentation Hardness of Materials

## 2.3 Definitions

Terms used in AMS are defined in AS7766 and as follows:

2.3.1 An alloy-depleted layer is defined as a loss of alloying elements at the surface sufficient to affect a near-surface microstructure difference, using a suitable etchant.

## 3. TECHNICAL REQUIREMENTS

### 3.1 Composition

Shall conform to the percentages by weight shown in Table 1, determined in accordance with AMS2283 or by other analytical methods acceptable to the purchaser.

**Table 1 - Composition**

| Element             | Min       | Max            |
|---------------------|-----------|----------------|
| Carbon              | 0.01      | 0.05           |
| Manganese           | --        | 0.35           |
| Silicon             | --        | 0.35           |
| Phosphorus          | 0.004     | 0.020          |
| Sulfur              | --        | 0.0025         |
| Chromium            | 17.00     | 21.00          |
| Cobalt              | 8.00      | 10.00          |
| Molybdenum          | 2.50      | 3.10           |
| Tungsten            | 0.80      | 1.40           |
| Columbium (Niobium) | 5.20      | 5.80           |
| Titanium            | 0.50      | 1.00           |
| Aluminum            | 1.20      | 1.70           |
| Boron               | 0.003     | 0.008          |
| Copper              | --        | 0.30           |
| Lead                | --        | 0.0005 (5 ppm) |
| Iron                | 8.00      | 10.00          |
| Nickel              | remainder |                |

3.1.1 The producer may test for any element not listed in Table 1 and include this analysis in the report of 4.4. Reporting of any element not listed in the composition table is not a basis for rejection unless limits of acceptability are specified by the purchaser.

### 3.1.2 Check Analysis

Composition variations shall meet the applicable requirements of AMS2269.

### 3.2 Melting Practice

Alloy shall be induction melted under vacuum and consumable electrode remelted.

### 3.3 Condition

The product shall be supplied in the following condition:

#### 3.3.1 Sheet, Strip, and Foil

Cold rolled, solution heat treated, and, unless solution heat treatment is performed in an atmosphere yielding a bright finish, descaled, and producing a uniform finish.

### 3.4 Solution Heat Treatment

#### 3.4.1 Product 0.050 Inch (1.27 mm) and Over in Thickness

Heat to a temperature set point within the range 1750 to 1825 °F (954 to 996 °C) and hold at the selected temperature set point within  $\pm 25$  °F ( $\pm 14$  °C) for a time commensurate with product thickness, and cool at a rate equivalent to an air cool or faster. Pyrometry shall be in accordance with AMS2750.

#### 3.4.2 Product Under 0.050 Inch (1.27 mm) in Thickness

No specific heat-treating instructions are specified, but it is recommended that the product be solution heat treated by heating in a suitable protective atmosphere, preferably in hydrogen or argon (see 3.4.3), or in vacuum ( $10^{-4}$  Torr or less), to a temperature set point within the range 1750 to 1825 °F (954 to 996 °C), and held at the selected temperature set point within  $\pm 25$  °F ( $\pm 14$  °C) for a time commensurate with product thickness, and cool at a rate equivalent to an air cool or faster.

The use of dissociated ammonia as protective atmosphere is not recommended.

3.4.2.1 For product 0.010 inch (0.25 mm) and under in nominal thickness, a dew point of -60 °F (-50 °C) or lower is preferable when using hydrogen or argon atmosphere.

### 3.4.3 Continuous Heat Treatment

When continuous annealing is used, process parameters (e.g., furnace temperature set points, heat input, travel rate, etc.) for continuous heat-treating lines shall be established by the producer and validated by testing of product to the requirements of 3.5.

## 3.5 Properties

Product, 0.1874 inch (4.76 mm) and under in nominal thickness, shall conform to the following requirements:

### 3.5.1 As Solution Heat Treated

#### 3.5.1.1 Tensile Properties

Tensile properties shall be as shown in Table 2, determined in accordance with ASTM E8/E8M.

**Table 2A - Tensile properties, inch/pound units**

| Nominal Thickness<br>Inches | Tensile<br>Strength<br>ksi, Max | Yield Strength<br>at 0.2% Offset<br>ksi, Max | Elongation in<br>2 Inches or 4D<br>%, Min |
|-----------------------------|---------------------------------|--|---|
| Up to 0.010, incl           | 175                             | 110  | report                                    |
| Over 0.010 to 0.1874, incl  | 175                             | 110  | 30  |

**Table 2B - Tensile properties, SI units**

| Nominal Thickness<br>Millimeters | Tensile<br>Strength<br>MPa, Max | Yield Strength<br>at 0.2% Offset<br>MPa, Max | Elongation in<br>50 mm or 4D<br>%, Min |
|----------------------------------|---------------------------------|--|--|
| Up to 0.25, incl                 | 1206                            | 758  | report                                 |
| Over 0.25 to 4.76, incl          | 1206                            | 758  | 30                                     |

#### 3.5.1.2 Hardness

Shall be not higher than shown in Table 3, or equivalent (see 8.2), determined in accordance with ASTM E18; for thin gages, where superficial hardness testing is impractical, microhardness testing in accordance with ASTM E384 may be used. Product shall not be rejected on the basis of hardness if the tensile properties of 3.5.1.1 are acceptable, determined on specimens taken from the same sample as that with nonconforming hardness or from another sample with similar nonconforming hardness.

**Table 3 - Maximum hardness**

| Nominal Thickness<br>Inches | Nominal Thickness<br>Millimeters | Hardness |
|-----------------------------|----------------------------------|----------|
| Up to 0.1874, incl          | Up to 4.760, incl                | 35 HRC   |

#### 3.5.1.3 Bending

Product 0.1874 inch (4.76 mm) and under in nominal thickness shall be tested in accordance with ASTM E290 using a sample prepared nominally 0.75 inch (19.0 mm) in width with its axis of bending parallel to the direction of rolling. Testing shall be performed at room temperature, through an angle of 180 degrees around a diameter equal to the bend factor times the nominal thickness of the product, in accordance with Table 4. The specimen shall exhibit no cracking, when visually examined. In case of dispute, the results of tests using the guided bend test of ASTM E290 shall govern.

**Table 4 - Bending parameters**

| Nominal Thickness<br>Inches | Nominal Thickness<br>Millimeters | Bend<br>Factor |
|-----------------------------|----------------------------------|----------------|
| Up to 0.050, incl           | Up to 1.27, incl                 | 1              |
| Over 0.050 to 0.1874, incl  | Over 1.27 to 4.760, incl         | 2              |

### 3.5.1.4 Average Grain Size

Shall be as follows, determined in accordance with ASTM E112:

#### 3.5.1.4.1 For Product 0.010 Inch (0.25 mm) and Under in Nominal Thickness

ASTM No. 8 or finer.

#### 3.5.1.4.2 For Product Over 0.010 to 0.1874 Inch (0.25 to 4.76 mm), Inclusive, in Nominal Thickness

ASTM No. 6 or finer.

### 3.5.1.5 Surface Microstructure

Metallographic examination on the unetched and etched specimen cross section of product 0.125 inch (3.18 mm) and under in thickness shall disclose no alloy depleted surface layer (see 2.3.1), intergranular attack, or other detrimental surface conditions greater than 0.0005 inch (0.013 mm) for product 0.060 inch (1.52 mm) and under in nominal thickness, or greater than 0.001 inch (0.03 mm) for product over 0.060 inch (1.52 mm) in nominal thickness. Other standards for acceptance or limits for product over 0.125 inch (3.18 mm) in thickness may be established by the purchaser. Each specimen shall be prepared according to ASTM E3 and evaluated at 500X magnification.

### 3.5.2 Response to Precipitation Heat Treatment

Samples from product shall have the following properties after being precipitation heat treated by heating to 1450 °F ± 15 °F (788 °C ± 8 °C), holding at heat for 8 hours ± 0.5 hour, cooling at a rate of 100 °F ± 15 °F (56 °C ± 8 °C) degrees per hour to 1300 °F ± 15 °F (704 °C ± 8 °C), holding at 1300 °F ± 15 °F (704 °C ± 8 °C) for 8 hours ± 0.5 hour, and cooling in air. Pyrometry shall be in accordance with AMS2750.

#### 3.5.2.1 Tensile Properties

##### 3.5.2.1.1 At Room Temperature

Room temperature tensile properties shall be as shown in Table 5, determined in accordance with ASTM E8/E8M.

**Table 5A - Minimum room temperature tensile properties - response to heat treatment, inch/pound units**

| Nominal Thickness<br>Inches | Tensile<br>Strength<br>ksi | Yield Strength<br>at 0.2% Offset<br>ksi | Elongation in<br>2 Inches or 4D<br>% |
|-----------------------------|----------------------------|---|--------------------------------------|
| Up to 0.010, incl           | 194                        | 138                                     | report                               |
| Over 0.010 to 0.1875, incl  | 194                        | 138                                     | 12                                   |

**Table 5B - Minimum room temperature tensile properties, SI units**

| Nominal Thickness<br>Millimeters | Tensile<br>Strength<br>MPa | Yield Strength<br>at 0.2% Offset<br>MPa | Elongation in<br>50 mm or 4D<br>% |
|----------------------------------|----------------------------|---|-----------------------------------|
| Up to 0.25, incl                 | 1338                       | 958                                     | report                            |
| Over 0.25 to 4.76, incl          | 1338                       | 958                                     | 12                                |

3.5.2.1.1.1 Unless otherwise specified, the strain rate shall be set at 0.005 in/in/min (0.005 mm/mm/min) and maintained within a tolerance of  $\pm 0.002$  in/in/min ( $\pm 0.002$  mm/mm/min) through 0.2% offset yield strain. After the yield strain, the speed of the testing machine shall be set between 0.05 in/in and 0.5 in/in (0.05 mm/mm and 0.5 mm/mm) of the length of the reduced parallel section (or distance between the grips for specimens not having a reduced section) per minute. Alternatively, an extensometer and strain rate indicator may be used to set the strain rate between 0.05 in/in/min and 0.5 in/in/min (0.05 mm/mm/min and 0.5 mm/mm/min). The requirement for compliance becomes effective for material produced 1 year after the publication date of this specification.

3.5.2.1.2 At 1300 °F (704 °C)

Elevated temperature tensile properties shall be as shown in Table 6, determined in accordance with ASTM E21 on specimens heated to 1300 °F  $\pm$  5 °F (704 °C  $\pm$  3 °C), held at heat for not less than 20 minutes before testing, and tested at 1300 °F  $\pm$  5 °F (704 °C  $\pm$  3 °C).

**Table 6A - Minimum elevated temperature tensile properties - response to heat treatment, inch/pound units**

| Nominal Thickness<br>Inches | Tensile<br>Strength<br>ksi | Yield Strength<br>at 0.2% Offset<br>ksi | Elongation in<br>2 Inches or 4D<br>% |
|-----------------------------|----------------------------|---|--------------------------------------|
| Up to 0.1874, incl          | 147                        | 117                                     | 5                                    |

**Table 6B - Minimum elevated temperature tensile properties - response to heat treatment, SI units**

| Nominal Thickness<br>Millimeters | Tensile<br>Strength<br>MPa | Yield Strength<br>at 0.2% Offset<br>MPa | Elongation in<br>50 mm or 4D<br>% |
|----------------------------------|----------------------------|---|-----------------------------------|
| Up to 4.76, incl                 | 1014                       | 807                                     | 5                                 |

3.5.2.1.2.1 For product 0.010 inch (0.25 mm) and under in nominal thickness, properties may be established using a sample up to 0.025 inch (0.64 mm) in nominal thickness from the same master coil and heat. The supplier's certification of test shall indicate the thickness at which the elevated temperature tensile test was performed. Properties do not apply to product 0.010 inch (0.25 mm) and under, but product shall be produced from product under 0.025 inch (0.64 mm) that has met property requirements.

3.5.2.2 Stress-Rupture Properties at 1300 °F (704 °C)

A tensile specimen, maintained at 1300 °F  $\pm$  3 °F (704 °C  $\pm$  2 °C) while a load sufficient to product the initial axial stress shown in Table 7 or higher stress is applied continuously, shall not rupture in less than 39 hours. Elongation after rupture, measured at room temperature, shall be not less than specified in Table 7. Tests shall be conducted in accordance with ASTM E139.

**Table 7A - Stress-rupture properties - response to heat treatment, inch/pound units**

| Nominal Thickness<br>Inches | Initial Axial<br>Stress, ksi | Elongation in<br>2 Inches or 4D<br>% |
|-----------------------------|------------------------------|--------------------------------------|
| Up to 0.015, incl           | 90                           | -                                    |
| Over 0.015 to 0.1874, incl  | 90                           | 4                                    |

**Table 7B - Stress-rupture properties, SI units**

| Nominal Thickness<br>Millimeters | Initial Axial<br>Stress, MPa | Elongation in<br>50 mm or 4D<br>% |
|----------------------------------|------------------------------|-----------------------------------|
| Up to 0.38, incl                 | 621                          | -                                 |
| Over 0.38 to 4.76, incl          | 621                          | 4                                 |

- 3.5.2.2.1 For product 0.010 inch (0.25 mm) and under in nominal thickness, stress-rupture properties may be established using a sample up to 0.025 inch (0.64 mm) in nominal thickness from the same master coil and heat. The supplier's certification of test shall indicate the thickness at which the stress-rupture test was performed. Properties do not apply to product 0.010 inch (0.25 mm) and under, but product shall be produced from product under 0.025 inch (0.64 mm) that has met property requirements.
- 3.5.2.2.2 The test of 3.5.2.3 may be conducted using incremental loading. In such case, the load required to produce the initial axial stress shown in Table 7 shall be used to rupture or for 39 hours, whichever occurs first. After the 39 hours and at intervals of 8 hours minimum thereafter, the stress shall be increased in increments of 5.0 ksi (34.5 MPa). Time to rupture and elongation requirements shall be as specified in 3.5.2.3.
- 3.5.3 Mechanical property requirements for product outside the range covered by 1.1 shall be agreed upon between the purchaser and producer and reported per 4.4.1.

### 3.6 Quality

The product, as received by the purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from imperfections detrimental to usage of the product.

### 3.7 Tolerances

Tolerances shall conform to all applicable requirements of AMS2262.

### 3.8 Exceptions

Any exceptions shall be authorized by the purchaser and reported as in 4.4.1.

## 4. QUALITY ASSURANCE PROVISIONS

### 4.1 Responsibility for Inspection

The producer of the product shall supply all samples for the producer's tests and shall be responsible for the performance of all required tests. The purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to specified requirements.

### 4.2 Classification of Tests

#### 4.2.1 Acceptance Tests

The following requirements are acceptance tests and shall be performed on each heat or lot as applicable:

Composition (see 3.1) of each heat and tolerances (see 3.7) of each lot

Tensile properties (see 3.5.1.1), hardness (see 3.5.1.2), bending (see 3.5.1.3), average grain size (see 3.5.1.4), and surface microstructure (see 3.5.1.5) of each lot as solution heat treated

Room temperature tensile properties (see 3.5.2.1.1) of each lot after precipitation heat treatment

#### 4.2.2 Periodic Tests

The following requirements are periodic tests and shall be performed at a frequency selected by the producer, unless frequency of testing is specified by the purchaser:

Tensile properties at 1300 °F (704 °C) (see 3.5.2.1.2) and stress-rupture properties (see 3.5.2.3) after precipitation heat treatment.

### 4.3 Sampling and Testing

Sampling and testing shall be in accordance with AMS2371.