



## Standard Specification for Nickel Alloy Forgings<sup>1</sup>

This standard is issued under the fixed designation B 564; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This specification has been approved for use by agencies of the Department of Defense.*

### 1. Scope

1.1 This specification<sup>2</sup> covers forgings of nickel alloy UNS N02200, Ni-Cu alloy UNS N04400, Ni-Cr-Fe alloys UNS N06600 and UNS N06690, Ni-Cr-Mo-Nb alloy UNS N06625, low-carbon Ni-Mo-Cr alloys UNS N10276 and UNS N06022, Ni-Cr-Mo-W alloy UNS N06110, low-carbon Ni-Cr-Mo-W alloy UNS N06686, Ni-Fe-Cr-Mo-Cu alloy UNS N08825, Fe-Ni-Cr-Mo-N alloy UNS N08367, low-carbon Ni-Cr-Mo alloy UNS N06059, low carbon nickel-chromium-molybdenum-copper alloy UNS N06200, Ni-Mo alloy UNS N10675, low-carbon Ni-Fe-Cr-Mo-Cu alloy UNS N08031, Ni-Cr-W-Mo alloy UNS N06230, Ni-Cr-Co-Mo alloy UNS N06617, Ni-Co-Cr-Si alloy UNS N12160, Ni-Fe-Cr alloys, Ni-Mo alloy UNS N10629, Ni-Cr-Fe-Al alloy UNS N06025, Ni-Cr-Fe-Si alloy UNS N06045, and low-carbon Cr-Ni-Fe-N alloy UNS R20033\*.

1.1.1 The nickel-iron-chromium alloys are UNS N08120, UNS N08800, UNS N08810, and UNS N08811. Alloy UNS N08800 is normally employed in service temperatures up to and including 1100°F (593°C). Alloys UNS N08810 and UNS N08811 are normally employed in service temperatures above 1100°F where resistance to creep and rupture is required, and are annealed to develop controlled grain size for optimum properties in this temperature range.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

- E 8 Test Methods for Tension Testing of Metallic Materials<sup>3</sup>
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications<sup>4</sup>
- E 76 Test Methods for Chemical Analysis of Nickel-Copper Alloys<sup>5</sup>
- E 112 Test Methods for Determining the Average Grain Size<sup>3</sup>

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee B-2 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.07 on Refined Nickel and Cobalt and Their Alloys.

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<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications see related Specification SB-564 in Section II of that Code.

\* New designations established in accordance with ASTM E 527 and SAE J1086, Practice for Numbering Metals and Alloys (UNS).

<sup>3</sup> Annual Book of ASTM Standards, Vol 03.01.

<sup>4</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>5</sup> Annual Book of ASTM Standards, Vol 03.05.

E 350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron<sup>5</sup>

E 1473 Test Methods for Chemical Analysis of Nickel, Cobalt, and High-Temperature Alloys<sup>6</sup>

### 3. Ordering Information

3.1 Orders for material to this specification shall include information with respect to the following:

3.1.1 Alloy (Table 1).

3.1.2 Condition (Table 3).

3.1.3 Quantity (mass or number of pieces).

3.1.4 Forging, sketch or drawing.

3.1.5 *Certification*—State if certification or a report of test results is required (Section 14).

3.1.6 *Samples for Product (Check) Analysis*—Whether samples for product (check) analysis should be furnished (see 4.2).

3.1.7 *Purchaser Inspection*—If the purchaser wishes to witness tests or inspection of material at the place of manufacture, the purchase order must so state indicating which tests or inspections are to be witnessed (Section 12).

### 4. Chemical Composition

4.1 The material shall conform to the composition limits specified in Table 1.

4.2 If a product (check) analysis is performed by the purchaser, the material shall conform to the product (check) analysis variations in Table 2.

### 5. Mechanical Properties and Other Requirements

5.1 *Mechanical Properties*—The material shall conform to the mechanical properties specified in Table 3.

5.2 *Grain Size*—Annealed alloys (UNS N08810 and UNS N08811) shall conform to an average grain size of ASTM No. 5 or coarser.

### 6. Dimensions and Permissible Variations

6.1 Dimensions and tolerances shall be as specified on the applicable forging sketch or drawing.

### 7. Workmanship, Finish, and Appearance

7.1 The material shall be uniform in quality and condition, sound, and free of injurious imperfections.

<sup>6</sup> Annual Book of ASTM Standards, Vol 03.06.



TABLE 1 Chemical Requirements

| Element                   | Composition, %                 |                                       |                                       |                                       |                                       |                                       |  |   |                                       |   |  |   |
|---------------------------|--------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|--|---|---------------------------------------|---|--|---|
|                           | Nickel-Copper Alloy UNS N04400 | Nickel-Chromium-Iron Alloy UNS N06600 | Nickel-Chromium-Iron Alloy UNS N06690 | Nickel-Iron Chromium Alloy UNS N08120 | Nickel-Iron-Chromium Alloy UNS N08800 | Nickel-Iron-Chromium Alloy UNS N08810 | Nickel-Chromium-Iron-Aluminum Alloy UNS N06025 | Nickel-Chromium-Iron-Silicon Alloy UNS N06045 | Nickel-Iron-Chromium Alloy UNS N08811 | Nickel-Chromium-Molybdenum-Columbium Alloy UNS N06625 | Nickel-Chromium-Molybdenum-Tungsten Alloy UNS N06110 | Nickel-Iron-Chromium-Molybdenum-Copper Alloy UNS N08825 |
| Nickel                    | 63.0 <sup>A</sup> min          | 72.0 <sup>A</sup> min                 | 58.0 min <sup>A</sup>                 | 35.0–39.0                             | 30.0–35.0                             | 30.0–35.0                             | balance  | 45 min  | 30.0–35.0                             | 58.0 min <sup>A</sup>                                 | 51.0 min <sup>A</sup>                                | 38.0–46.0   |
| Copper                    | 28.0–34.0                      | 0.5 max                               | 0.5 max                               | 0.50 max                              | 0.75 max                              | 0.75 max                              | 0.10 max                                       | 0.3 max                                       | 0.75 max                              | ...   | 0.50 max   | 1.5–3.0   |
| Iron                      | 2.5 max                        | 6.0–10.0                              | 7.0–11.0                              | remainder                             | 39.5 min <sup>A</sup>                 | 39.5 min <sup>A</sup>                 | 8.0–11.0                                       | 21.0–25.0                                     | 39.5 min <sup>A</sup>                 | 5.0 max   | 1.0 max  | 22.0 min <sup>A</sup>                                   |
| Manganese                 | 2.0 max                        | 1.0 max                               | 0.5 max                               | 1.5                                   | 1.5 max                               | 1.5 max                               | 0.15   | 1.0   | 1.5 max                               | 0.5 max   | 1.0 max  | 1.0 max   |
| Carbon                    | 0.3 max                        | 0.15 max                              | 0.05 max                              | 0.02–0.10                             | 0.10 max                              | 0.05–0.10                             | 0.15–0.25                                      | 0.05–0.12                                     | 0.06–0.10                             | 0.10 max  | 0.15 max   | 0.05 max  |
| Silicon                   | 0.5 max                        | 0.5 max                               | 0.5 max                               | 1.0                                   | 1.0 max                               | 1.0 max                               | 0.5  | 2.5–3.0                                       | 1.0 max                               | 0.5 max   | 1.0 max  | 0.5 max   |
| Sulfur, max               | 0.024                          | 0.015                                 | 0.015                                 | 0.03                                  | 0.015                                 | 0.015                                 | 0.01   | 0.010   | 0.015                                 | 0.015   | 0.015  | 0.03  |
| Chromium                  | ...                            | 14.0–17.0                             | 27.0–31.0                             | 23.0–27.0                             | 19.0–23.0                             | 19.0–23.0                             | 24.0–26.0                                      | 26.0–29.0                                     | 19.0–23.0                             | 20.0–23.0   | 29.0–33.0  | 19.5–23.5   |
| Aluminum                  | ...                            | ...                                   | ...                                   | 0.40 max                              | 0.15–0.60                             | 0.15–0.60                             | 1.8–2.4  | ...   | 0.15–0.60                             | 0.4 max   | 1.0 max  | 0.2 max   |
| Titanium                  | ...                            | ...                                   | ...                                   | 0.20 max                              | 0.15–0.60                             | 0.15–0.60                             | 0.1–0.2  | ...   | 0.15–0.60                             | 0.4 max   | 1.0 max  | 0.6–1.2   |
| Columbium (Nb) + tantalum | ...                            | ...                                   | ...                                   | 0.4–0.9                               | ...                                   | ...                                   | ...  | ...   | ...                                   | 3.15–4.15   | 0.10–1.0   | ...   |
| Molybdenum                | ...                            | ...                                   | ...                                   | 2.50 max                              | ...                                   | ...                                   | ...  | ...   | ...                                   | 8.0–10.0  | 9.0–12.0   | 2.5–3.5   |
| Phosphorus                | ...                            | ...                                   | ...                                   | 0.040 max                             | ...                                   | ...                                   | 0.02 max                                       | 0.02 max                                      | ...                                   | 0.015 max   | 0.50 max   | ...   |
| Tungsten                  | ...                            | ...                                   | ...                                   | 2.50 max                              | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Cobalt, max               | ...                            | ...                                   | ...                                   | 3.0                                   | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Vanadium, max             | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Nitrogen                  | ...                            | ...                                   | ...                                   | 0.15–0.30                             | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Boron                     | ...                            | ...                                   | ...                                   | 0.010 max                             | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Lanthanum                 | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Aluminum + Titanium       | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | ...   | 0.85–1.20                             | ...   | ...  | ...   |
| Nickel + Molybdenum       | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Columbium (Nb) max        | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Tantalum, max             | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | ...   | ...                                   | ...   | ...  | ...   |
| Zirconium, max            | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | 0.01–0.10                                      | ...   | ...                                   | ...   | ...  | ...   |
| Cerium                    | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | ...  | 0.03–0.09                                     | ...                                   | ...   | ...  | ...   |
| Yttrium                   | ...                            | ...                                   | ...                                   | ...                                   | ...                                   | ...                                   | 0.05–0.12                                      | ...   | ...                                   | ...   | ...  | ...   |

<sup>A</sup> Element shall be determined arithmetically by difference.

8. Sampling

8.1 Lot Definition:

8.1.1 A lot for chemical analysis shall consist of one heat.

8.1.2 A lot for mechanical properties and grain size testing shall consist of all material from the same heat, size, finish, condition, and processed at one time.

8.2 Test Material Selection:

8.2.1 Chemical Analysis—Representative samples shall be taken during pouring or subsequent processing.

8.2.1.1 Product (check) analysis shall be wholly the responsibility of the purchaser.

8.2.2 Mechanical Properties and Grain Size—Samples of the material to provide test specimens for mechanical properties and grain size shall be taken from such locations in each lot as to be representative of that lot.

9. Number of Tests

9.1 Chemical Analysis—One test per lot.

9.2 Mechanical Properties—One test per lot.

9.3 Grain Size—For alloys N08810 and UNS N08811, one test per lot.

10. Specimen Preparation

10.1 The tension test specimen representing each lot shall be taken from a forging or from a test prolongation.

10.2 The axis of the specimen shall be located at any point

midway between the center and the surface of solid forgings and at any point midway between the inner and outer surfaces of the wall of hollow forgings, and shall be parallel to the direction of greatest metal flow.

10.3 The specimens shall be the largest possible round type shown in Test Methods E 8.

11. Test Methods

11.1 The chemical composition, mechanical, and other properties of the material as enumerated in this specification shall be determined, in case of disagreement, in accordance with the following methods:

| Test               | ASTM Designation    |
|--------------------|---------------------|
| Chemical Analysis  | E 76, E 350, E 1473 |
| Tension            | E 8                 |
| Rounding Procedure | E 29                |
| Grain Size         | E 112               |

11.2 The measurement of average grain size may be carried out by the planimetric method, the comparison method, or the intercept method described in Test Methods E 112. In case of dispute, the “referee” method for determining average grain size shall be the planimetric method.

11.3 For purposes of determining compliance with the specified limits for requirements of the properties listed in the following table, an observed value, or a calculated value, shall be rounded as indicated as follows, in accordance with the rounding method of Practice E 29:



TABLE 1 Continued

| Element             | Composition, %   |  |   |  |   |  |  |  |                                    |                                    |   |   |                         |  |
|---------------------|--|--|---|--|---|--|--|--|------------------------------------|------------------------------------|---|---|-------------------------|--|
|                     | Low-Carbon Nickel-Molybdenum-Chromium Alloy UNS N10276 | Low-Carbon Nickel-Molybdenum-Chromium Alloy UNS N06022 | Iron-Nickel-Chromium-Molybdenum-Nitrogen Alloy UNS N06367 | Low-Carbon Nickel-Chromium-Molybdenum Alloy UNS N06059 | Low-Carbon Nickel-Chromium-Molybdenum-Copper Alloy UNS N06200 | Low-Carbon Nickel-Iron-Chromium-Molybdenum-Copper Alloy UNS N06031 | Nickel-Chromium-Tungsten-Molybdenum Alloy UNS N06230 | Nickel-Chromium-Cobalt-Molybdenum Alloy UNS N06617 | Nickel-Molybdenum Alloy UNS N10629 | Nickel-Molybdenum Alloy UNS N10675 | Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy UNS N06686 | Nickel-Cobalt-Chromium-Silicon Alloy UNS N12160 | Nickel Alloy UNS N02200 | Chromium-Nickel-Iron-Nitrogen Alloy UNS R20033 |
| Nickel              | remainder <sup>A</sup>                                 | remainder <sup>A</sup>                                 | 23.50-25.50   | balance <sup>A</sup>                                   | remainder <sup>A</sup>  | 30.0-32.0  | remainder <sup>A</sup>                               | 44.5 min   | balance                            | 65.0 min                           | remainder   | remainder <sup>A</sup>                          | 99.0 <sup>A</sup> min   | 30.0-33.0                                      |
| Copper              | ...  | ...  | 0.75 max  | ...  | 1.3-1.9   | 1.0-1.4  | ...  | 0.5 max  | 0.5 max                            | 0.20 max                           | ...   | ...   | 0.25 max                | 0.30-1.20                                      |
| Iron                | 4.0-7.0  | 2.0-6.0  | remainder <sup>A</sup>                                    | 1.5 max  | 3.0 max   | balance <sup>A</sup>   | 3.0 max  | 3.0 max  | 1.0-6.0                            | 1.0-3.0                            | 5.0 max   | 3.5 max   | 0.40 max                | balance <sup>A</sup>                           |
| Manganese           | 1.0 max  | 0.50 max   | 2.00 max  | 0.5 max  | 0.50 max  | 2.0 max  | 0.30-1.00  | 1.0 max  | 1.5                                | 3.0 max                            | 0.75 max  | 1.5 max   | 0.35 max                | 2.0  |
| Carbon              | 0.010 max  | 0.015 max  | 0.030 max   | 0.010 max  | 0.010 max   | 0.015 max  | 0.05-0.15  | 0.05-0.15  | 0.010 max                          | 0.01 max                           | 0.010 max   | 0.15 max  | 0.15 max                | 0.015 max                                      |
| Silicon             | 0.08 max   | 0.08 max   | 1.00 max  | 0.10 max   | 0.08 max  | 0.3 max  | 0.25-0.75  | 1.0 max  | 0.05                               | 0.10 max                           | 0.06 max  | 2.4-3.0   | 0.35 max                | 0.50   |
| Sulfur, max         | 0.03   | 0.02   | 0.030   | 0.005  | 0.010   | 0.010  | 0.015  | 0.015  | 0.01                               | 0.010                              | 0.02  | 0.015   | 0.01                    | 0.01   |
| Chromium            | 14.5-16.5  | 20.0-22.5  | 20.0-22.0   | 22.0-24.0  | 22.0-24.0   | 26.0-28.0  | 20.0-24.0  | 20.0-24.0  | 0.5-1.5                            | 1.0-3.0                            | 19.0-23.0   | 26.0-30.0                                       | ...                     | 31.0-35.0                                      |
| Aluminum            | ...  | ...  | ...   | 0.1-0.4  | 0.5 max   | ...  | 0.20-0.50  | 0.8-1.5  | 0.1-0.5                            | 0.50 max                           | ...   | ...   | ...                     | ...  |
| Titanium            | ...  | ...  | ...   | ...  | ...   | ...  | ...  | 0.6 max  | ...                                | 0.20 max                           | 0.02-0.25   | 0.20-0.80                                       | ...                     | ...  |
| Columbium (Nb)      | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | ...                                | ...   | ...   | ...                     | ...  |
| + tantalum          | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | ...                                | ...   | ...   | ...                     | ...  |
| Molybdenum          | 15.0-17.0  | 12.5-14.5  | 6.00-7.00   | 15.0-16.5  | 15.0-17.0   | 6.0-7.0  | 1.0-3.0  | 8.0-10.0   | 26.0-30.0                          | 27.0-32.0                          | 15.0-17.0   | 1.0 max   | ...                     | 0.50-2.0                                       |
| Phosphorus          | 0.04 max   | 0.02 max   | 0.040 max   | 0.015 max  | 0.025 max   | 0.020 max  | 0.030 max  | ...  | 0.04 max                           | 0.030 max                          | 0.04 max  | 0.030 max                                       | ...                     | 0.02 max                                       |
| Tungsten            | 3.0-4.5  | 2.5-3.5  | ...   | ...  | ...   | ...  | 13.0-15.0  | ...  | ...                                | 3.0 max                            | 3.0-4.4   | 1.0 max   | ...                     | ...  |
| Cobalt              | 2.5 max  | 2.5 max  | ...   | 0.3 max  | 2.0 max   | ...  | 5.0 max  | 10.0 min-15.0 max                                  | 2.5                                | 3.0 max†                           | ...   | 27.0-33.0†                                      | ...                     | ...  |
| Vanadium, max       | 0.35   | 0.35   | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | 0.20                               | ...   | ...   | ...                     | ...  |
| Nitrogen            | ...  | ...  | 0.18-0.25   | ...  | ...   | 0.15-0.25  | ...  | ...  | ...                                | ...                                | ...   | ...   | ...                     | 0.35-0.60                                      |
| Boron               | ...  | ...  | ...   | ...  | ...   | ...  | 0.015 max  | 0.006 max  | ...                                | ...                                | ...   | ...   | ...                     | ...  |
| Lanthanum           | ...  | ...  | ...   | ...  | ...   | ...  | 0.005-0.050  | ...  | ...                                | ...                                | ...   | ...   | ...                     | ...  |
| Aluminum + Titanium | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | ...                                | ...   | ...   | ...                     | ...  |
| Nickel + Molybdenum | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | 94.0-98.0                          | ...   | ...   | ...                     | ...  |
| Columbium (Nb), max | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | 0.20                               | ...   | 1.0   | ...                     | ...  |
| Tantalum, max       | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | 0.20                               | ...   | ...   | ...                     | ...  |
| Zirconium, max      | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | 0.10                               | ...   | ...   | ...                     | ...  |
| Cerium              | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | ...                                | ...   | ...   | ...                     | ...  |
| Yttrium             | ...  | ...  | ...   | ...  | ...   | ...  | ...  | ...  | ...                                | ...                                | ...   | ...   | ...                     | ...  |

<sup>A</sup> Element shall be determined arithmetically by difference.  
 † Editorially corrected.

| Test                             | Rounded Unit for Observed or Calculated Value                               |
|----------------------------------|---|
| Chemical composition             | nearest unit in the last right-hand place of figures of the specified limit |
| Tensile strength, yield strength | nearest 1000 psi (6.9 MPa)  |
| Elongation                       | nearest 1 %   |
| Grain size:                      |   |
| 0.0024 in. (0.060 mm) or larger  | nearest multiple of 0.0002 in. (0.005 mm)                                   |
| less than 0.0024 in. (0.060 mm)  | nearest multiple of 0.0001 in. (0.002 mm)                                   |

12. Inspection

12.1 Inspection of the material by the purchaser shall be made as agreed upon between the purchaser and the seller as part of the purchase contract.

13. Rejection and Reheating

13.1 Material, tested by the purchaser, that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction

with the results of the test, the producer or supplier may make claim for a reheating.

14. Certification

14.1 When specified in the purchase order or contract, a manufacturer's certification shall be furnished to the purchaser stating that material has been manufactured, tested, and inspected in accordance with this specification, and that the test results on representative samples meet specification requirements. When specified in the purchase order or contract, a report of the test results shall be furnished.

15. Product Marking

15.1 The material shall be marked legibly with the name of the material, this specification number, the heat number and condition, and such other information as may be defined in the contract or order.

16. Keywords

16.1 nickel alloy forgings

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**TABLE 2 Product (Check) Analysis Chemical Composition Variations**

| Element                   | Specified Limit of Element, % | Variation under min. or over max of the Specified Limit of Element |
|---------------------------|-------------------------------|--|
| Nickel                    | over 20.00 to 30.00, incl     | 0.25   |
|                           | over 30.00 to 40.00, incl     | 0.30   |
|                           | over 40.00 to 60.00, incl     | 0.35   |
|                           | over 60.00 to 80.00, incl     | 0.45   |
|                           | over 80.00 to 99.00, incl     | 0.60   |
| Copper                    | up to 0.20, incl              | 0.02   |
|                           | over 0.20 to 0.50, incl       | 0.03   |
|                           | over 0.50 to 5.00, incl       | 0.04   |
|                           | over 20.00 to 30.00, incl     | 0.15   |
| Iron                      | over 30.00 to 40.00, incl     | 0.20   |
|                           | up to 0.20, incl              | 0.02   |
|                           | over 0.20 to 0.75, incl       | 0.03   |
|                           | over 0.75 to 2.50, incl       | 0.05   |
|                           | over 2.50 to 5.00, incl       | 0.07   |
|                           | over 5.00 to 10.00, incl      | 0.10   |
| Manganese                 | over 10.00 to 15.00, incl     | 0.15   |
|                           | over 30.00 to 50.00, incl     | 0.45   |
|                           | up to 1.00, incl              | 0.03   |
| Carbon                    | over 1.00 to 3.00, incl       | 0.04   |
|                           | up to 0.02, incl              | 0.005  |
| Silicon                   | over 0.02 to 0.20, incl       | 0.01   |
|                           | over 0.20 to 0.60, incl       | 0.02   |
|                           | over 0.05 to 0.25, incl       | 0.02   |
|                           | over 0.25 to 0.50, incl       | 0.03   |
| Sulfur                    | over 0.50 to 1.00, incl       | 0.05   |
|                           | over 1.00 to 4.50, incl       | 0.10   |
|                           | up to 0.02, incl              | 0.003  |
| Chromium                  | over 0.02 to 0.060, incl      | 0.005  |
|                           | up to 5.0, incl               | 0.10   |
|                           | over 5.00 to 15.00, incl      | 0.15   |
| Aluminum                  | over 15.00 to 25.00, incl     | 0.25   |
|                           | over 25.00 to 35.00, incl     | 0.30   |
|                           | over 0.10 to 0.50, incl       | 0.05   |
|                           | over 0.50 to 2.00, incl       | 0.10   |
| Titanium                  | over 2.00 to 5.00, incl       | 0.20   |
|                           | over 0.10 to 0.50, incl       | 0.03   |
|                           | over 0.50 to 1.00, incl       | 0.04   |
| Columbium (Nb) + tantalum | over 1.00 to 2.00, incl       | 0.05   |
|                           | up to 1.50, incl              | 0.05   |
|                           | over 1.50 to 3.00, incl       | 0.10   |
| Molybdenum                | over 3.0 to 5.0, incl         | 0.15   |
|                           | up to 1.00, incl              | 0.03   |
|                           | over 1.00 to 3.00, incl       | 0.05   |
|                           | over 3.00 to 5.00, incl       | 0.10   |
| Phosphorus                | over 5.0 to 20.0, incl        | 0.15   |
|                           | over 20.00 to 30.00, incl     | 0.25   |
|                           | over 30.00 to 40.00, incl     | 0.35   |
|                           | up to 0.04, incl              | 0.005  |
| Tungsten                  | up to 1.00, incl              | 0.04   |
|                           | over 1.50 to 3.00, incl       | 0.10   |
|                           | over 3.00 to 5.00, incl       | 0.15   |
| Cobalt                    | over 10.0 to 20.0, incl       | 0.25   |
|                           | over 0.20 to 1.00, incl       | 0.03   |
|                           | over 1.00 to 5.00, incl       | 0.05   |
|                           | over 25.00 to 30.00, incl     | 0.30   |
| Vanadium                  | over 30.00 to 35.00, incl     | 0.35   |
|                           | up to 0.50, incl              | 0.04   |
| Nitrogen                  | up to 0.25, incl              | 0.01   |
|                           | over 0.25 to 0.35, incl       | 0.030  |
|                           | over 0.35 to 0.45, incl       | 0.040  |
|                           | over 0.45 to 0.60, incl       | 0.050  |
| Boron                     | up to 0.20, incl              | 0.005  |
|                           | up to 0.01, incl              | 0.002  |
| Lanthanum                 | up to 0.20, incl              | 0.005  |
| Zirconium                 | up to 0.10, incl              | 0.01   |
| Cerium                    | up to 0.050, incl             | 0.005  |
|                           | over 0.050 to 0.10, incl      | 0.010  |
| Yttrium                   | over 0.10 to 0.20, incl       | 0.015  |
|                           | up to 0.50, incl              | 0.005  |
|                           | over 0.050 to 0.10, incl      | 0.010  |
|                           | over 0.10 to 0.20, incl       | 0.015  |



TABLE 3 Mechanical Property Requirements<sup>A</sup>

| Material and Condition   | Maximum Section Thickness, in. (mm)                            | Tensile Strength, min, ksi (MPa) | Yield Strength, 0.2 % Offset, min, ksi (MPa) | Elongation in 2 in. or 50 mm or 4D, min, % |
|--|--|----------------------------------|--|--|
| Nickel alloy UNS N02200, annealed                                | ...  | 55 (380)                         | 15 (105)                                     | 40   |
| Nickel-copper alloy UNS N04400, annealed                         | ...  | 70 (483)                         | 25 (172)                                     | 35   |
| Nickel-chromium-iron alloy UNS N06600, annealed                  | ...  | 80 (552)                         | 35 (241)                                     | 30   |
| UNS N06690, annealed   | ...  | 85 (586)                         | 35 (241)                                     | 30   |
| Low-carbon nickel-chromium molybdenum alloy UNS N06059           | ...  | 100 (690)                        | 45 (310)                                     | 45   |
| Low-carbon nickel-chromium-molybdenum-copper alloy UNS N06200    | ...  | 100 (690)                        | 41 (283)                                     | 45   |
| Nickel-iron-chromium alloys:                                     |  |                                  |  |  |
| Annealed (alloy UNS N08120)                                      | ...  | 90 (621)                         | 40 (276)                                     | 30   |
| Annealed (alloy UNS N08800)                                      | ...  | 75 (517)                         | 30 (207)                                     | 30   |
| Annealed (alloys UNS N08810 and UNS N08811)                      | ...  | 65 (448)                         | 25 (172)                                     | 30   |
| Nickel-chromium-molybdenum-columbium alloy UNS N06625, annealed  | up to 4 (102), incl over 4 <sup>B</sup> (102) to 10 (254) incl | 120 (827)                        | 60 (414)                                     | 30   |
|  |  | 110 (758)                        | 50 (345)                                     | 25   |
| Nickel-chromium-molybdenum-tungsten alloy UNS N06110, annealed   | up to 4 (102), incl over 4 (102) to 10 (254), incl             | 95 (655)                         | 45 (310)                                     | 60   |
|  |  | 90 (621)                         | 40 (276)                                     | 50   |
| Nickel-iron-chromium-molybdenum-copper alloy UNS N08825          | ...  | 85 (586)                         | 35 (241)                                     | 30   |
| Low carbon nickel-molybdenum-chromium alloy UNS N10276, annealed | ...  | 100 (690)                        | 41 (283)                                     | 40   |

TABLE 3 Continued

| Material and Condition  | Maximum Section Thickness, in. (mm) | Tensile Strength, min, ksi (MPa) | Yield Strength, 0.2 % Offset, min, ksi (MPa) | Elongation in 2 in. or 50 mm or 4D, min, % |
|---|-------------------------------------|----------------------------------|--|--|
| Low-carbon nickel-molybdenum-chromium alloy UNS N06022                      | ...                                 | 100 (690)                        | 45 (310)                                     | 45   |
| Iron-nickel-chromium-molybdenum-nitrogen alloy UNS N08367                   | ...                                 | 95 (655)                         | 45 (310)                                     | 30   |
| Low-carbon nickel-iron-chromium-molybdenum-copper alloy UNS N08031          | ...                                 | 94 (650)                         | 40 (276)                                     | 40   |
| Nickel-chromium-tungsten-molybdenum alloy UNS N06230, annealed <sup>C</sup> | ...                                 | 110 (758)                        | 45 (310)                                     | 40   |
| Nickel-chromium-cobalt-molybdenum alloy UNS N06617                          | ...                                 | 95 (655)                         | 35 (241)                                     | 35   |
| Nickel-molybdenum alloy UNS N10675, annealed                                | ...                                 | 110 (760)                        | 51 (350)                                     | 40   |
| Low-carbon nickel-chromium-molybdenum-tungsten alloy UNS N06686             | ...                                 | 100 (690)                        | 45 (310)                                     | 45   |
| Nickel-cobalt-chromium-silicon alloy UNS N12160, annealed                   | ...                                 | 90 (620)                         | 35 (240)                                     | 40   |
| Low-carbon chromium-nickel-iron-nitrogen alloy UNS R20033                   | ...                                 | 109 (750)                        | 55 (380)                                     | 40   |
| Nickel-molybdenum alloy UNS N10629, annealed                                | ...                                 | 110 (760)                        | 51 (350)                                     | 40   |
| Nickel-chromium-iron-aluminum alloy UNS N06025, annealed                    | ...                                 | 94 (650)                         | 43 (300)                                     | 35   |
| Nickel-chromium-iron-silicon alloy UNS N06045, annealed                     | ...                                 | 90 (620)                         | 35 (240)                                     | 35   |

<sup>A</sup> Forging quality is furnished to chemical requirements and surface inspection only.

<sup>B</sup> Over 4 to 10-in. (102 to 254-mm) diameter for parts machined from forged bar.

<sup>C</sup> Solution annealed at a minimum temperature of 2150°F (1177°C) followed by a water quench or rapidly cooled by other means.

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