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<th>DATE</th>
<th>DESCRIPTION</th>
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<tr>
<td>D-1</td>
<td>02/12/14</td>
<td>Index For Stamping Dies Cast Materials</td>
</tr>
<tr>
<td>D-2</td>
<td>02/03/15</td>
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<td>D-11</td>
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<td>Non-Alloyed Gray Cast Iron (G2500/NAAMS)</td>
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<td>D-11.1</td>
<td>02/03/15</td>
<td>Low-Alloyed Gray Cast Iron (G25HP/NAAMS)</td>
</tr>
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<td>D-12</td>
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<td>Alloyed Gray Cast Iron (G3500/NAAMS)</td>
</tr>
<tr>
<td>D-13</td>
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<td>Non-Alloyed Ferritic Ductile Iron (D4512/NAAMS)</td>
</tr>
<tr>
<td>D-14</td>
<td>10/29/07</td>
<td>Pearlitic Ductile Iron (D5506/NAAMS) (Discontinued)</td>
</tr>
<tr>
<td>D-15</td>
<td>02/03/15</td>
<td>Refined Pearlitic Ductile Iron (D6510/NAAMS)</td>
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<td>D-16</td>
<td>08/01/11</td>
<td>Non-Alloyed Steel (S0030/NAAMS)</td>
</tr>
<tr>
<td>D-17</td>
<td>02/12/14</td>
<td>Alloyed Steel (S0050A/NAAMS)</td>
</tr>
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<td>D-18</td>
<td>08/01/11</td>
<td>Medium Shock/Medium Wear Resistant Tool Steel (TA2/NAAMS)</td>
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<td>D-19</td>
<td>08/01/11</td>
<td>High Wear/Low Shock Resistant Tool Steel (TD2/NAAMS)</td>
</tr>
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<td>D-20</td>
<td>08/01/11</td>
<td>High Shock/Low Wear Resistant Tool Steel (TS7/NAAMS)</td>
</tr>
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<td>D-21</td>
<td>08/01/11</td>
<td>Alloyed Steel (S7140/NAAMS)</td>
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<td>D-22</td>
<td>08/01/11</td>
<td>Alloyed Steel (S2333/NAAMS)</td>
</tr>
<tr>
<td>D-23</td>
<td>02/03/15</td>
<td>Refined Pearlitic Ductile Iron (D7003/NAAMS)</td>
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</tbody>
</table>
1. SCOPE
This specification encompasses criteria for stamping dies cast materials delivered in the rough-cast condition.

1.1 TYPES
This specification covers ferrous casting materials used for stamping dies. These materials include: G2500/NAAMS, G25HP/NAAMS, G3500/NAAMS, D4512/NAAMS, D5506/NAAMS, D6510/NAAMS, S0030/NAAMS, S0050A/NAAMS, S7140/NAAMS, S2333/NAAMS, TA2/NAAMS, TD2/NAAMS, and TS7/NAAMS. This specification does not include or cover wrought materials.

1.2 PROPERTIES
The properties of all castings are sensitive to section size, particularly the properties of gray and ductile irons. Since the cooling rate varies with thickness, the microstructure and properties will vary with thickness as well. Therefore, all properties must be referenced to specific test methods and test sample locations.

1.3 APPLICATIONS
The application of these materials is automotive stamping dies.

1.4 MATERIAL DESCRIPTIONS
Brief descriptions are listed below for the materials covered in this specification.

G2500/NAAMS: Non-Alloyed Gray Cast Iron (not surface hardenable)
G25HP NAAMS: High Pearlite Low-Alloyed Gray Cast Iron
G3500/NAAMS: Alloyed Gray Cast Iron (surface hardenable)
D4512/NAAMS: Non-Alloyed Ferritic Ductile Iron (not surface hardenable)
D6510/NAAMS: Refined Alloyed Pearlitic Ductile Iron (surface hardenable)
D7003/NAAMS: Refined Alloyed Pearlitic Ductile Iron (surface hardenable)
S0030/NAAMS: Non-Alloyed Steel (not surface hardenable)
S0050A/NAAMS: Alloyed Steel (surface hardenable)
S2333/NAAMS: Alloyed Steel (surface or through hardenable)
S7140/NAAMS: Alloyed Steel (surface hardenable)
TA2/NAAMS: Medium Shock/Medium Wear Resistant Tool Steel
TD2/NAAMS: High Wear/Low Shock Resistant Tool Steel
TS7/NAAMS: High Shock/Low Wear Resistant Tool Steel

The prefix on each alloy designation indicates the type of alloy as listed below.

G  Gray Iron
D  Ductile (Nodular) Iron
S  Steel
T  Tool Steel

1.5 SAFETY-HAZARDOUS MATERIALS
While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials or procedures, this specification does not address those hazards that may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials or process and to take any necessary precautionary measures to ensure the health and safety of all personnel involved.
2. TEST PROCEDURES

2.1 COMPOSITION

Chemical analysis of cast iron shall be made from chilled samples only. Cast iron chemical analysis shall be determined according to appropriate Standard Test Methods included in Volumes 03.05 and 03.06 of the Annual Book of ASTM Standards. The preferred method for carbon and sulfur determination is according to ASTM E 1019. If alloys are added by inoculation, after taking the chilled sample, calculated recovery amounts shall be noted and added to the analysis. Chemistry checks for steel shall be determined by emission spectroscopy or wet method for all elements according to ASTM A751.

2.2 MICROSTRUCTURE

2.2.1 CAST IRON

The microstructure for cast iron, except for G2500/NAAMS, shall be determined using the casting coupon shown in Figure 1. This coupon may be attached to the casting on or close to a working surface, or may be located on a representative section of the casting.

The microstructure shall be determined in the center of the smaller diameter cross-section.

If required, the microstructure for G2500/NAAMS can be checked using a small representative section from the casting.

Metallographic preparation shall be done according to ASTM E 3. The graphite characteristics shall be determined by ASTM A 247. The matrix microstructure shall be evaluated by quantitative image analysis. If such equipment is unavailable, it is acceptable to use a visual comparison with the Gray Iron or Ductile Iron Microstructures Rating Chart at 100x. These charts are available in poster form from the AFS (American Foundry Society, Inc).
2.2.2 CAST STEEL
Microstructures of steel castings may be determined from small samples taken on or close to the working surface of the die. Grain size is to be determined according to ASTM E 112.

2.3 HARDNESS
Hardness shall be measured on the casting or on the working surface of the coupon shown in Figure 1. The surface to be checked shall be flat and free of any porosity, inclusions, and decarburization. A minimum of 3.0 mm is to be ground or machined from the casting surface prior to hardness checking. Care must be taken not to burn the surface and cause hairline crack.

All hardness measuring equipment shall be checked using standard blocks and/or calibrated according to the manufacturer’s recommended procedures prior to making any hardness checks.

The Brinell hardness test is the preferred method for as-cast samples, performed according to ASTM specification E 10 or E 110 at a load of 3000 kg.

The Rockwell hardness test is the preferred method for hardened samples, performed according to ASTM specification E 18 or E 118.

Electronic rebound type testers providing a digital readout in Brinell are acceptable. A minimum of three (3) hardness measurements shall be made for each area checked.

If there is any discrepancy or question of conformance, the Brinell or Rockwell test, as described above, shall be the arbiter.

2.4 TENSILE TESTING
Standard tensile testing may be done to determine tensile strength, yield strength, and elongation.

Samples for gray iron shall come from a separately cast type C test bar in accordance with ASTM A 48.

Samples for ductile iron shall come from 75 mm Y blocks in accordance with ASTM A 536. As an alternative, samples for ductile iron may come from “cast on” 25 mm keel blocks per Figure 2. Samples for steel shall come from keel blocks in accordance with ASTM A781.

Sample preparation and subsequent testing shall be in accordance with ASTM E8 for Iron and ASTM A370 for Steel.

The presence of porosity, shrink, inclusions, or other discontinuities within the fracture area invalidates the test, and the data must be discarded. The viewing of such discontinuities shall be done without the use of any magnifying device.
SPECIAL NOTE:
BOTH LEGS CAN BE CUT FROM
THE KEEL BLOCK AND USED
FOR TENSILE TEST BARS

Figure 2 Cast-On Keel Block
3. MECHANICAL PROPERTIES

3.1 GENERAL
The microstructure and mechanical properties, specifically hardness and strength, are the primary requirements for grading and classifying the castings in this specification.

Samples shall be retained by the foundry for 5 years to enable analysis of microstructure and mechanical properties when required. All mechanical properties shall meet or exceed the minimum product requirements.

3.2 COMPOSITION
The composition ranges are given in Table 1. Composition shall be measured as described in Section 2.1.

3.3 MICROSTRUCTURE
The microstructure requirements are given in Tables 2a and 2b. Microstructures are to be determined as described in Sections 2.2 and 3.1.

3.4 MECHANICAL PROPERTIES
The mechanical properties are given in Table 3. Casting hardness shall be measured as described in Section 2.3. Strength and elongation shall be measured as described in Section 2.4.

Note: the tensile properties are from the type C test bar, Y block, or keel block only. Sections taken from the die itself may not meet the specification for tensile properties due to variations caused by changes in section thickness.
## Table 1
Composition Requirements (Weight Percent)*

<table>
<thead>
<tr>
<th>Material #/NAAMS</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Cu</th>
<th>V</th>
<th>Mg</th>
<th>S (max)</th>
<th>P (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2500</td>
<td>2.9-3.5</td>
<td>1.9-2.3</td>
<td>0.5-0.9</td>
<td>0.25 max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>G25HP</td>
<td>3.0-3.4</td>
<td>1.7-2.3</td>
<td>0.5-1.0</td>
<td>0.60 max</td>
<td></td>
<td></td>
<td></td>
<td>0.8 max</td>
<td></td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>G3500</td>
<td>2.8-3.2</td>
<td>1.5-2.2</td>
<td>0.7-1.0</td>
<td>0.35-0.50</td>
<td>0.35-0.50</td>
<td></td>
<td></td>
<td>0.7 max</td>
<td></td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>D4512</td>
<td>3.25-3.75</td>
<td>2.25-2.60</td>
<td>0.2-0.5</td>
<td>0.25 max</td>
<td></td>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td></td>
<td>0.015</td>
<td>0.080</td>
</tr>
<tr>
<td>D6510</td>
<td>3.0-3.8</td>
<td>2.0-2.4</td>
<td>0.3-0.6</td>
<td>0.12 max</td>
<td>0.35-0.50</td>
<td>0.5-1.5</td>
<td>0.35-1.0</td>
<td></td>
<td>0.040-0.060</td>
<td>0.012</td>
<td>0.05</td>
</tr>
<tr>
<td>D7003</td>
<td>3.0-3.8</td>
<td>2.0-2.4</td>
<td>0.4-0.8</td>
<td>0.12 max</td>
<td>0.4-0.6</td>
<td>0.8-1.2</td>
<td>0.8-1.2</td>
<td></td>
<td>0.030-0.065</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>S0030</td>
<td>0.20-0.30</td>
<td>0.3-0.5</td>
<td>0.5-0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
<td>0.045</td>
</tr>
<tr>
<td>S0050A</td>
<td>0.4-0.5</td>
<td>0.2-0.5</td>
<td>0.9-1.2</td>
<td>0.8-1.1</td>
<td>0.35-0.50</td>
<td></td>
<td></td>
<td></td>
<td>0.15 max</td>
<td>0.05</td>
<td>0.045</td>
</tr>
<tr>
<td>S2333</td>
<td>0.56-0.64</td>
<td>0.20-0.50</td>
<td>0.70-0.90</td>
<td>4.30-4.70</td>
<td>0.40-0.60</td>
<td></td>
<td></td>
<td>0.20-0.30</td>
<td></td>
<td>0.035</td>
<td>0.035</td>
</tr>
<tr>
<td>S7140</td>
<td>0.45-0.50</td>
<td>0.40-0.80</td>
<td>0.80-1.00</td>
<td>1.30-1.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.035</td>
<td>0.035</td>
</tr>
<tr>
<td>TA2</td>
<td>0.85-1.05</td>
<td>0.25-0.40</td>
<td>0.5-0.7</td>
<td>4.75-5.25</td>
<td>0.95-1.2</td>
<td></td>
<td></td>
<td>0.2-0.4</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>TD2</td>
<td>1.4-1.6</td>
<td>1.50 max</td>
<td>1.00 max</td>
<td>11.0-13.0</td>
<td>0.70-1.20</td>
<td></td>
<td></td>
<td>1.00 max</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>TS7</td>
<td>0.45-0.55</td>
<td>0.20-1.00</td>
<td>0.20-0.80</td>
<td>3.00-3.50</td>
<td>1.30-1.80</td>
<td></td>
<td></td>
<td>0.20-0.30</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*Trace amounts shall be limited to standard practice, so that there are no detrimental microstructure or mechanical property effects.*
### Table 2a
Cast Iron Microstructure Specifications - (100X)

<table>
<thead>
<tr>
<th>Material #/NAAMS</th>
<th>Graphite Type</th>
<th>Flake Size or Nodule Count</th>
<th>Nodularity (min)</th>
<th>Pearlite*</th>
<th>Ferrite*</th>
<th>Carbide* (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2500</td>
<td>Type A</td>
<td>4-6</td>
<td>n/a</td>
<td>50% min</td>
<td>45% max</td>
<td>5%</td>
</tr>
<tr>
<td>G25HP</td>
<td>Type A</td>
<td>4-7</td>
<td>n/a</td>
<td>75% min</td>
<td>10% max</td>
<td>5%</td>
</tr>
<tr>
<td>G3500</td>
<td>Type A</td>
<td>4-6</td>
<td>n/a</td>
<td>87% min</td>
<td>10% max</td>
<td>3%</td>
</tr>
<tr>
<td>D4512</td>
<td>I &amp; II</td>
<td>50/mm² min</td>
<td>85%</td>
<td>10% max</td>
<td>87% min</td>
<td>3%</td>
</tr>
<tr>
<td>D6510</td>
<td>I &amp; II</td>
<td>100/mm² min</td>
<td>90%</td>
<td>70-90%</td>
<td>10-30%</td>
<td>0.5%</td>
</tr>
<tr>
<td>D7003</td>
<td>I &amp; II</td>
<td>50/mm² min</td>
<td>85% min</td>
<td>80-100%</td>
<td>0-15%</td>
<td>5% max</td>
</tr>
</tbody>
</table>

* Note that the pearlite, ferrite, and carbide contents add up to 100% for the matrix microstructure. Microstructure results are for approved test bars as specified in Section 2.4. Actual casting microstructure may vary as previously described in Section 1.2.

### Table 2b
Steel Microstructure Specifications (annealed)

<table>
<thead>
<tr>
<th>Material #/NAAMS</th>
<th>ASTM Grain Size</th>
<th>Microstructure (100x)</th>
<th>% Carbide</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0030</td>
<td>Not Specified</td>
<td>Homogenous mixture of ferrite and pearlite</td>
<td>3% max</td>
<td></td>
</tr>
<tr>
<td>S0050A</td>
<td>#5 or finer</td>
<td>Homogenous mixture of pearlite and ferrite</td>
<td>5% max</td>
<td></td>
</tr>
<tr>
<td>S7140</td>
<td>#5 or finer</td>
<td>Homogenous mixture of pearlite and ferrite and no dendritic structure</td>
<td>5% max</td>
<td></td>
</tr>
<tr>
<td>S2333</td>
<td>#5 or finer</td>
<td>Homogenous mixture of pearlite and ferrite and no dendritic structure</td>
<td>5% max</td>
<td></td>
</tr>
<tr>
<td>TA2</td>
<td>Not Specified</td>
<td>Homogenous mixture of pearlite and ferrite</td>
<td>Not Specified</td>
<td></td>
</tr>
<tr>
<td>TD2</td>
<td>Not Specified</td>
<td>Homogenous mixture of pearlite and ferrite</td>
<td>Not Specified</td>
<td></td>
</tr>
<tr>
<td>TS7</td>
<td>Not Specified</td>
<td>Homogenous mixture of pearlite and ferrite</td>
<td>Not Specified</td>
<td></td>
</tr>
</tbody>
</table>

No dendritic structure
3.5 SURFACE QUALITY

All as-cast surfaces shall meet specified criteria for discontinuities. Acceptance criteria shall be based on ASTM A802 for steel and ASTM A834 for iron. Acceptance levels utilize SCRATA (Steel Casting Research And Trade Association) graded reference comparators. Acceptance levels shall be as follows:

<table>
<thead>
<tr>
<th>Category</th>
<th>Plate No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Surface Texture (cold shuts, cracks, sand burn in)</td>
<td>[A3]</td>
</tr>
<tr>
<td>(B) Nonmetallic Inclusions</td>
<td>[B4]</td>
</tr>
<tr>
<td>(C) Gas Porosity</td>
<td>[C3]</td>
</tr>
<tr>
<td>(D) Fusion Discontinuities</td>
<td>[D2]</td>
</tr>
<tr>
<td>(E) Expansion Discontinuities (scabs)</td>
<td>[E3]</td>
</tr>
<tr>
<td>(G) Metal Removal Marks – Thermal (riser/gates)</td>
<td>[G3]</td>
</tr>
<tr>
<td>(H) Metal Removal Marks – Mechanical</td>
<td>[H4]</td>
</tr>
<tr>
<td>(J) Weld</td>
<td>[J3]</td>
</tr>
</tbody>
</table>

4. HEAT TREATMENT

It is mandatory that all castings requiring furnace stress relief and annealing be processed as specified for each individual alloy. It is the suppliers responsibility to assure that hardnnesses and microstructures, for all cast materials, conform to those specified in Tables 2a, 2b, and 3.
5. IDENTIFICATION
   Each casting shall be identified with the NAAMS material number as listed in
   Section 1.4.

6. INSPECTION AND REJECTION
   The purchaser reserves the right to sample incoming shipments, even though it is the
   responsibility of the supplier to meet the requirements without dependence upon the
   purchaser’s inspection. Frequency of testing is to be agreed upon between the
   purchaser and the supplier.

   6.1 COMPOSITION
       The purchaser reserves the right to reject any casting if the value of any
       element falls outside the limits listed in Table 1. However, since microstructure
       and mechanical properties are the primary requirements for this specification,
       as stated in Section 3.1, their conformance shall be a consideration in any
       out-of-specification situation.

   6.2 MICROSTRUCTURE
       The purchaser reserves the right to reject any casting if the microstructure
       does not meet the requirements listed in Tables 2a and 2b.
       The microstructure shall be determined as described in Sections 2.2 and 3.1.

   6.3 HARDNESS
       For large casting with multiple hardness checks, the purchaser reserves the
       right to reject any casting if more than 20% of the hardness measurements
       taken fall outside the hardness limits listed in Table 3. Hardness shall be
       measured as described in Section 2.3.

   6.4 MECHANICAL PROPERTIES
       The purchaser reserves the right to reject any casting, if the tensile sample
       representative of the casting exhibits a tensile strength, yield strength, or elongation
       below the values listed in Table 3. Mechanical properties shall be measured as
       described in Section 2.4.

   6.5 SURFACE QUALITY
       The purchaser reserves the right to reject a casting that exhibits a surface
       discontinuity as described and referenced in Section 3.5

7. ORIGIN
   This standard was originated by the Auto/Steel Partnership’s NAAMS Die Materials
   Subcommittee, November, 2002.
1. MECHANICAL PROPERTIES
   Hardness: 163-212 HBW
   Minimum Tensile Strength: 205 MPa

2. MICROSTRUCTURE (100X)
   Flake Type: Type A 70% min
   Pearlite: 50% min
   Flake Size: 4-6
   Ferrite: 45% max
   Carbide: 5% max

3. COMPOSITION (in weight %)*
   Carbon (C) 2.9-3.5
   Chromium (Cr) 0.25 max
   Silicon (Si) 1.9-2.3
   Sulfur (S) 0.20 max
   Manganese (Mn) 0.5-0.9
   Phosphorus (P) 0.20 max

   * Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   Castings shall be left in the mold until they have cooled to approximately 260°C or less.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
LOW-ALLOYED GRAY CAST IRON (G25HP/NAAMS)

1. MECHANICAL PROPERTIES
   Hardness: 175-235 HBW
   Minimum Tensile Strength: 280 MPa

2. MICROSTRUCTURE (100X)
   Pearlite: 75% min
   Carbide: 5% max

3. COMPOSITION (in weight %)*
   Carbon (C) 3.0-3.4 Copper (CU) 0.8 max
   Silicon (Si) 1.7-2.3 Sulfur (S) 0.12 max
   Manganese (Mn) 0.5-1.0 Phosphorus (P) 0.12 max
   Chromium (Cr) 0.60 max

   * Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

   † Chromium and Copper amounts are to be adjusted by foundry so all sizes of castings can meet the hardness required.

4. HEAT TREATMENT
   Castings shall be left in the mold until they have cooled to approximately 260°C or less.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
ALLOYED GRAY CAST IRON
(G3500/NAAMS)

1. MECHANICAL PROPERTIES (Stress-Relieved)
   Hardness: 197-241 HBW
   Minimum Tensile Strength: 310 MPa

2. MICROSTRUCTURE (100X)
   Flake Type: Type A 80%min
   Flake Size: 4-6
   Pearlite: 87% min
   Ferrite: 10% max
   Carbide: 3% max

3. COMPOSITION (in weight %)*
   Carbon (C) 2.8-3.2
   Silicon (Si) 1.5-2.2
   Manganese (Mn) 0.7-1.0
   Chromium (Cr) 0.35-0.50
   Molybdenum (Mo) 0.35-0.50
   Copper (Cu) 0.7 max
   Sulfur (S) 0.15 max
   Phosphorus (P) 0.15 max

* Trace amounts shall be limited to standard practice so that there are no detrimental
   microstructure or mechanical property effects.

4. HEAT TREATMENT
   Castings shall be left in the mold until they have cooled to approximately 260°C or less.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General
   Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Subcritical Annealed)
   - Hardness: 143-190 HBW
   - Minimum Tensile Strength: 415 MPa
   - Minimum Yield Strength: 310 MPa
   - Minimum Elongation: 12%

2. MICROSTRUCTURE (100X)
   - Nodule Type: I & II
   - Pearlite: 10% max
   - Nodule Count: 50/mm² min
   - Ferrite: 87% min
   - Nodularity: 85% min
   - Carbide: 3% max

3. COMPOSITION (in weight %)*
   - Carbon (C) 3.25-3.75
   - Chromium (Cr) 0.25 max
   - Silicon (Si) 2.25-2.60
   - Sulfur (S) 0.015 max
   - Manganese (Mn) 0.2-0.5
   - Phosphorus (P) 0.080 max
   - Nickel (Ni) 0.5-1.0

   * Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   Castings shall be left in the mold until they have cooled to approximately 260°C or less.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. **MECHANICAL PROPERTIES (Stress Relieved)**
   - Hardness: 190-241 BHN
   - Minimum Tensile Strength: 550 MPa
   - Minimum Yield Strength: 380 MPa
   - Minimum Elongation: 6%

2. **MICROSTRUCTURE (100X)**
   - Nodule Type: I & II Pearlite: 87% min
   - Nodule Count: 50/mm² min Ferrite: 10% max
   - Nodularity: 85% min Carbide: 3% max

3. **COMPOSITION (in weight %)*
   - Carbon (C): 3.0-3.8
   - Copper (Cu): 0.3-0.7 (optional)**
   - Silicon (Si): 2.0-2.6
   - Chromium (Cr): 0.025 max
   - Manganese (Mn): 0.5-1.0
   - Sulfur (S): 0.015 max
   - Molybdenum (Mo): 0.35-0.50
   - Phosphorus (P): 0.08 max
   - Nickel (Ni): 0.5-1.0

   * Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

   **The addition of copper promotes pearlite formation. It is typically added for large castings or castings with large section thicknesses.

4. **HEAT TREATMENT**
   All D5506/NAAMS castings shall be furnace stress relieved by holding at 565-595°C for a minimum of one hour plus one hour per 25 mm of section thickness (using the maximum section thickness). Castings shall be cooled at a maximum rate of 55°C per hour to 260°C or lower followed by cooling in still air.

5. **SURFACE QUALITY**
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. **INSPECTION AND REJECTION**
   For any deviation from the above designations refer to General Information Section 6.
REFINED
PEARLITIC DUCTILE IRON
(D6510/NAAMS)

1. MECHANICAL PROPERTIES (Stress Relieved)
   Hardness: 190-248 HBW
   Minimum Tensile Strength: 570 MPa
   Minimum Yield Strength: 350 MPa
   Minimum Room Temperature Charpy ISO 148-1
   2 mm U-notch (root radius 1 mm)
   with a depth of 2 mm 3 Joules
   Minimum Elongation: 4%

2. MICROSTRUCTURE (100X)
   Nodule Type: I & II Ferrite: 10-30%
   Nodule Count: 100/mm² min Pearlite: 70-90%
   Nodularity: 90% min Carbide: 0.5% max

   This specification requires bull’s-eye nodule structure.

3. COMPOSITION (in weight %)**
   Carbon (C) 3.0-3.8 Copper (Cu) 0.35-1.0
   Silicon (Si) 2.0-2.4 Chromium (Cr) 0.12 max
   Manganese (Mn) 0.3-0.6 Sulfur (S) 0.02 max
   Molybdenum (Mo) 0.35-0.50 Phosphorus (P) 0.05 max
   Nickel (Ni) 0.5-1.5 Magnesium (Mg) 0.040-0.060

   ** Trace amounts shall be limited to standard practice so that there are no detrimental
   microstructure or mechanical property effects.

4. HEAT TREATMENT
   Castings shall be left in the mold until they have cooled to approximately 260°C or less.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General
   Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   Hardness: 120-170 HBW
   Minimum Tensile Strength: 450 MPa
   Minimum Yield Strength: 240 MPa
   Minimum Elongation: 24 %

2. MICROSTRUCTURE (100X)
   Homogenous mixture of ferrite and pearlite and no dendritic structure
   Carbide: 3 % max

3. COMPOSITION (in weight percent)*
   Carbon (C): 0.20-0.30
   Sulfur (S): 0.05 max
   Silicon (Si): 0.3-0.5
   Phosphorus (P): 0.045 max
   Manganese (Mn): 0.5-0.7

* Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   All S0030/NAAMS castings shall be annealed by heating to 860-895°C and holding for a minimum of one hour plus one hour per 25 mm of section thickness (using the maximum section thickness). Castings shall be furnace cooled to 600°C at a rate not to exceed 45°C per hour then air cooled to room temperature.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   - Hardness: 170-229 HBW
   - Minimum Tensile Strength: 585 MPa
   - Minimum Yield Strength: 310 MPa
   - Minimum Elongation: 16%

2. MICROSTRUCTURE (100X)
   - Homogenous mixture of pearlite and ferrite and no dendritic structure,
   - ASTM grain size #5 or finer
   - Carbide: 5 % max

3. COMPOSITION (in weight percent)*
   - Carbon (C): 0.4-0.5
   - Molybdenum (Mo): 0.35-0.50
   - Silicon (Si): 0.2-0.5
   - Vanadium (V): 0.15 max
   - Manganese (Mn): 0.9-1.2
   - Sulfur (S): 0.05 max
   - Chromium (Cr): 0.8-1.1
   - Phosphorus (P): 0.045 max

* Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   - All S0050A/NAAMS castings shall be annealed by heating to 872-925°C and holding for a minimum of one hour plus one hour per 25 mm of section thickness using maximum section thickness. Castings shall be furnace cooled to 560°C at a rate not to exceed 45°C per hour, then air cooled at room temperature.

5. SURFACE QUALITY
   - All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   - For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   Hardness: 201-229 HBW

2. MICROSTRUCTURE (100X)
   Homogenous mixture of pearlite and ferrite and no dendritic structure.

3. COMPOSITION (in weight percent)*
   Carbon (C): 0.85-1.05  Molybdenum (Mo): 0.95-1.20
   Silicon (Si): 0.25-0.40  Vanadium (V): 0.2-0.4
   Manganese (Mn): 0.5-0.7  Sulfur (S): 0.03 max
   Chromium (Cr): 4.75-5.25  Phosphorus (P): 0.03 max
   * Trace amounts shall be limited to standard practice so that there are no detrimental micro-
     structure or mechanical property effects.

4. HEAT TREATMENT
   All TA2/NAAMS castings shall be annealed by heating slowly and uniformly to
   845-870°C and holding for a minimum of one hour plus one hour per 25 mm of
   section thickness using the maximum section thickness. Castings shall be cooled at a
   maximum rate of 35°C per hour to 540°C then air cooled to room temperature.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General
   Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   Hardness: 217-255 HBW

2. MICROSTRUCTURE (100X)
   Homogenous mixture of pearlite and ferrite and no dendritic structure.

3. COMPOSITION (in weight percent)*
   Carbon (C): 1.4-1.6  Molybdenum (Mo): 0.70-1.20
   Silicon (Si): 1.50 max  Vanadium (V): 1.00 max
   Manganese (Mn): 1.00 max  Sulfur (S): 0.03 max
   Chromium (Cr): 11.0-13.0  Phosphorus (P): 0.03 max

   * Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   All TD2/NAAMS castings shall be annealed by heating slowly and uniformly to 870-900°C and holding for a minimum of one hour plus one hour per 25 mm of section thickness using the maximum section thickness. Castings shall be cooled at a maximum rate of 35°C per hour to 540°C then air cooled to room temperature.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   Hardness: 187-223 HBW

2. MICROSTRUCTURE (100X)
   Homogenous mixture of pearlite and ferrite and no dendritic structure.

3. COMPOSITION (in weight percent)*
   Carbon (C): 0.45-0.55  Molybdenum (Mo): 1.30-1.80
   Silicon (Si): 0.20-1.00  Vanadium (V): 0.20-0.30
   Manganese (Mn): 0.20-0.80  Sulfur (S): 0.03 max
   Chromium (Cr): 3.00-3.50  Phosphorus (P): 0.03 max

* Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   All TS7/NAAMS castings shall be annealed by heating uniformly to 815-845°C and holding for a minimum of one hour plus one hour per 25 mm of section thickness using the maximum section thickness. Castings shall be cooled at a maximum rate of 35°C per hour to 540°C then air cooled to room temperature.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   - Hardness: 190-230 HBW
   - Minimum Tensile Strength: 600 MPa
   - Minimum Yield Strength: 450 MPa
   - Minimum Elongation: 10%

2. MICROSTRUCTURE (100X)
   Homogenous mixture of pearlite and ferrite and no dendritic structure,
   - ASTM grain size: #5 or finer
   - Carbide: 5% max

3. COMPOSITION (in weight percent)*
   - Carbon (C): 0.45-0.50
   - Sulphur (S): 0.035 Max
   - Silicon (Si): 0.40-0.80
   - Phosphorus (P): 0.035 Max
   - Manganese (Mn): 0.80-1.00
   - Chromium (Cr): 1.30-1.70

   * Trace amounts shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   Castings can be delivered annealed or pre-hardened condition per instructions of the purchaser. Pre-hardened casting are typically used for trim steels weighing 20 kg or less.

   Annealed: Heat to 840-880°C and hold for a minimum of one hour plus one hour per 25mm of section thickness using maximum section thickness. Castings shall be furnace cooled to 560°C at a rate not to exceed 45°C per hour, then air cooled at room temperature.

   Pre-Hardened: Heat to 840-880°C and hold 25 minutes at temperature. Quench with a cooling speed of 15°C per minute. Temper tool as soon as temperature reaches 50-70°C. Temper twice at 560-600°C. Final hardness should be 29-36 Rc.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designations refer to General Information Section 6.
1. MECHANICAL PROPERTIES (Annealed)
   Maximum Hardness: 190-230 HBW
   Minimum Tensile Strength 700 MPa
   Minimum Yield Strength 330 MPa
   Minimum Elongation 7 %

2. MICROSTRUCTURE (100X)
   Homogenous mixture of pearlite and ferrite and no dendritic structure
   ASTM grain size #5 or finer
   Carbide 5 % max

3. COMPOSITION (in weight percent)*
   Carbon (C) 0.56-0.64
   Molybdenum (Mo) 0.40-0.60
   Silicon (Si) 0.20-0.50
   Vanadium (V) 0.20-0.30
   Manganese (Mn) 0.70-0.90
   Sulphur (S) 0.035 Max
   Chromium (Cr) 4.30-4.70
   Phosphorus (P) 0.035 Max

* Trace amounts of tramp elements shall be limited to standard practice so that there are no detrimental microstructure or mechanical property effects.

4. HEAT TREATMENT
   Castings can be delivered in the annealed or pre-hardened condition per instructions of the purchaser. Pre-hardened castings are typically used for trim steels weighing 20 kg or less
   Annealed: Heat to 840-880°C and hold for a minimum of one hour plus one hour per 25 mm of section thickness using the maximum section thickness. Castings shall be furnace cooled to 770°C at a rate not to exceed 20°C per hour, continue cooling in furnace until 650°C at a rate not to exceed 10°C/hr, then air cooled at room temperature.
   Pre-Hardened: Pre-heat to 600-750°C and hold for one hour. Heat to 950-970°C and hold for a minimum of one hour plus one hour per 25 mm of section thickness using the maximum section thickness. Air quench with a cooling speed of 15°C per minute. Temper tool as soon as temperature reaches 50-70°C. Temper twice at approximately 675°C. Minimum holding time at temperature is 2 hours. Temper twice. Adjust tempering temperature as necessary to reach final hardness. Final hardness should be 280-340 HBW.

5. CLEANLINESS
   Metallic Inclusions per ASTM E45A*
   Type A Thin 1.5 Max
   Type A Heavy 1.5 Max
   Type B Thin 1.5 Max
   Type B Heavy 1.5 Max
   Type C Thin 1.5 Max
   Type C Heavy 1.5 Max
   Type D Thin 1.5 Max
   Type D Heavy 1.5 Max
   Sum of all metallic inclusions of all types is not to exceed 5.0
   % Porosity and Oxide per ASTM E1245 is not to exceed 0.20
   * ASTM E45A is adapted for use here despite the absence of reduction through work.

6. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

7. INSPECTION AND REJECTION
   For any deviation from the above designation refer to General Information Section 6.
1. MECHANICAL PROPERTIES
   Maximum Hardness: 190-300 HBW
   Minimum Tensile Strength: 700 MPa
   Minimum Yield Strength: 420 MPa
   Minimum Elongation: 2%

2. MICROSTRUCTURE (100X)
   Nodule Type: I & II
   Pearlite: 80-100%
   Nodule Count: 50/mm² min
   Ferrite: 0-15%
   Nodularity: 85% min
   Carbide: 5% max

3. COMPOSITION (in weight %)
   Carbon (C) 3.0-3.8
   Copper (Cu) 0.8-1.2
   Silicon (Si) 2.0-2.4
   Chromium (Cr) 0.12 Max
   Manganese (Mn) 0.4-0.8
   Sulphur (S) 0.02 Max
   Molybdenum (Mo) 0.4-0.6
   Phosphorus (P) 0.05 Max
   Nickel (Ni) 0.8-1.2
   Magnesium (Mg) 0.030-0.065

   ** Trace amounts shall be limited to standard practice so there is no detrimental microstructure or mechanical property effects.**

4. HEAT TREATMENT
   Castings shall be left in the mold until they have cooled to approximately 260°C or less.

5. SURFACE QUALITY
   All castings must be free of any rejectable surface defects, as described in General Information Section 3.5.

6. INSPECTION AND REJECTION
   For any deviation from the above designation refer to General Information Section 6.