FND™ (W)
15NiMoSiCr10

Carburizing steel for high service temperature

CONTINUOUS METALLURGICAL INNOVATION

SPECIAL STEELS DEVELOPMENT

RESEARCH SERVICE

Enhancing your performance
THE INDUSTRIAL ENVIRONMENT

Numerous applications require hard surfaces resistant to abrasion coupled with tough, ductile cores. These parts can be obtained with local carburizing of low carbon steel grades. Carburizing solutions are often limited in terms of resistance to temperature, unless the materials are heavily alloyed (cobalt,...).

Aubert & Duval has developed a simple solution which can be oil or gas quenched and tempered at a temperature up to 300 °C / 572 °F, FND. This solution is used in the aerospace industry, motor racing, injection systems...

DEVELOPMENT OF THE GRADE FND

The following criteria have been taken into account for the development of this grade:

- Capable of the UTS and YS of the main solutions available (9310, 9315, S82) after gas quenching,
- High ductility and fracture toughness,
- Capable of large parts with oil quenching,
- Retaining high surface hardness after tempering at 300 °C / 572 °F.
FND

15NiMoSiCr10

CHARACTERISTICS OF THE GRADE

FND (W) is designed for modern heat and surface treatment facilities:

• Low pressure (2 - 5 bars) gas quenching:
  - No oil quenching: saves cost of degreasing and effluent treatment.
  - High mechanical properties: reduce weight and increase performance.

• High temperature resistance:
  - Operating temperature up to 250 °C / 482 °F: increases performance.

APPLICATIONS

• Heavily loaded gears for the aerospace industry,
• Gears for motor racing,
• Any transmission part operating up to 250 °C / 482 °F (shafts, …)
• Injection systems,…
FND

15NiMoSiCr10

CHEMICAL COMPOSITION

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>min.</td>
<td>0.10</td>
<td>--</td>
<td>0.90</td>
<td>0.80</td>
<td>2.30</td>
<td>1.70</td>
<td>--</td>
</tr>
<tr>
<td>max.</td>
<td>0.20</td>
<td>1.00</td>
<td>1.30</td>
<td>1.20</td>
<td>2.70</td>
<td>2.20</td>
<td>0.50</td>
</tr>
</tbody>
</table>

SPECIFICATIONS

- 15NiMoSiCr10
- UNS: K51570
- AMS: 6494 (Air melted)
  6495 (Remelted)
## COMPARISON OF DIFFERENT CASE HARDENING STEELS

<table>
<thead>
<tr>
<th>A&amp;D Grades</th>
<th>Designations</th>
<th>Use temperature</th>
<th>C</th>
<th>Si</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>FADC (W)</td>
<td>10NiCrMo13-5 9310 AMS: 6265</td>
<td>&lt; 100 °C</td>
<td>0.10</td>
<td>0.10</td>
<td>3.25</td>
<td>1.20</td>
<td>0.10</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FADH (W)</td>
<td>14NiCrMo13-4 BS: S157 - 1.6657</td>
<td>&lt; 100 °C</td>
<td>0.16</td>
<td>0.25</td>
<td>3.20</td>
<td>1.00</td>
<td>0.25</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FADS (W)</td>
<td>16NiCrMo16-5 BS: S82 - 1.6723</td>
<td>&lt; 100 °C</td>
<td>0.16</td>
<td>--</td>
<td>4.25</td>
<td>1.20</td>
<td>0.20</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>BXM</td>
<td>18CrNiMo7-6 1.6587</td>
<td>&lt; 100 °C</td>
<td>0.17</td>
<td>0.30</td>
<td>1.60</td>
<td>1.60</td>
<td>0.30</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>50NILYW</td>
<td>13MeCrNi42-16-14 M50NIL</td>
<td>&lt; 400 °C</td>
<td>0.13</td>
<td>--</td>
<td>3.40</td>
<td>4.15</td>
<td>4.25</td>
<td>1.20</td>
<td>--</td>
</tr>
<tr>
<td>FDG (W)</td>
<td>20NiCrMo13 1.6660 AMS: 6492 - 6493</td>
<td>&lt; 100 °C</td>
<td>0.20</td>
<td>0.20</td>
<td>3.20</td>
<td>1.00</td>
<td>0.50</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FND (W)</td>
<td>15NiMoSiCr10 AMS: 6494 - 6495</td>
<td>&lt; 250 °C</td>
<td>0.15</td>
<td>1.10</td>
<td>2.50</td>
<td>1.00</td>
<td>2.00</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

AMS 6308
0.90Si - 1.0Cr - 2.0Ni - 3.2Mo - 2.0Cu - 0.10V (0.07 - 0.13C)

< 100 °C | 0.10 | 1.00 | 2.00 | 1.00 | 3.25 | 0.10 | 2.00 |

## COMPARISON OF THE CORE CHARACTERISTICS OF DIFFERENT CASE HARDENING STEELS

<table>
<thead>
<tr>
<th>A&amp;D Grades</th>
<th>Designations</th>
<th>Heat Treatment*</th>
<th>UTS (MPa/Ksi)</th>
<th>0.2% YS (MPa/Ksi)</th>
<th>E (%)</th>
<th>KV (J/ft.lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FADC (W)</td>
<td>10NiCrMo13-5 9310 AMS: 6265</td>
<td>825°C / Oil - 75°C / 150°C</td>
<td>1150 / 167</td>
<td>900 / 131</td>
<td>14</td>
<td>140 / 103</td>
</tr>
<tr>
<td>FADH (W)</td>
<td>14NiCrMo13-4 BS: S157 - 1.6657</td>
<td>825°C / Oil - 75°C / 150°C</td>
<td>1350 / 196</td>
<td>1000 / 145</td>
<td>14</td>
<td>140 / 103</td>
</tr>
<tr>
<td>FADS (W)</td>
<td>16NiCrMo16-5 BS: S82 - 1.6723</td>
<td>825°C / Oil - 75°C / 150°C</td>
<td>1450 / 210</td>
<td>1150 / 167</td>
<td>12</td>
<td>65 / 48</td>
</tr>
<tr>
<td>BXM</td>
<td>18CrNiMo7-6 1.6587</td>
<td>825°C / Oil - 75°C / 150°C</td>
<td>1400 / 203</td>
<td>1150 / 167</td>
<td>12</td>
<td>75 / 55</td>
</tr>
<tr>
<td>50NILYW</td>
<td>13MeCrNi42-16-14 M50NIL</td>
<td>1100°C / Oil - 75°C / 3 x 540°C</td>
<td>1400 / 203</td>
<td>1200 / 174</td>
<td>15</td>
<td>12 / 9</td>
</tr>
<tr>
<td>FDG (W)</td>
<td>20NiCrMo13 1.6660 AMS: 6492 - 6493</td>
<td>825°C / Oil - 75°C / 150°C</td>
<td>1450 / 210</td>
<td>1100 / 160</td>
<td>13</td>
<td>130 / 96</td>
</tr>
<tr>
<td>FND (W)</td>
<td>15NiMoSiCr10 AMS: 6494 - 6495</td>
<td>960°C / Gas - 75°C / 300°C</td>
<td>1350 / 196</td>
<td>1000 / 145</td>
<td>13</td>
<td>110 / 81</td>
</tr>
</tbody>
</table>

AMS 6308
0.90Si - 1.0Cr - 2.0Ni - 3.2Mo - 2.0Cu - 0.10V (0.07 - 0.13C)

913°C / Oil - 75°C / 2 x 200°C | 1172 / 170 | 965 / 140 | 16 | 118 / 87 |

* After carburizing + annealing

UNS: K51570
AMS 6494 (Air Melted), 6495 (Remelted)
FND

15NiMoSiCr10

TRANSFORMATION POINTS

<table>
<thead>
<tr>
<th>Phase</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ</td>
<td>960 °C / 1760 °F</td>
</tr>
<tr>
<td>Ac1</td>
<td>750 °C / 1382 °F</td>
</tr>
<tr>
<td>Ac3</td>
<td>930 °C / 1706 °F</td>
</tr>
<tr>
<td>Ms</td>
<td>380 °C / 716 °F</td>
</tr>
</tbody>
</table>

CCT DIAGRAM
MACROSTRUCTURE

The segregation, as measured on the ingots, complies with the tightest requirements. Below is an example for remelted grades for the aerospace industry:

<table>
<thead>
<tr>
<th>Classe</th>
<th>Type</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Freckles</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>White spots</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>Radial segregation</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>Ring pattern</td>
<td>B</td>
</tr>
</tbody>
</table>

Macrostructure according to ASTM A 604

CLEANLINESS

The typical values in terms of cleanliness are better than the usual requirements for such a remelted grade.

Typical values according to ASTM E45

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thin</td>
<td>Thick</td>
<td>Thin</td>
<td>Thick</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
MICROGRAPHIC CHARACTERIZATION

Annealed Condition
Heat to 860 °C / 1580 °F followed by slow cooling
Brinell hardness: < 285
Heat treated condition

Case Hardening

Heat treatment to apply:
- 960 °C / 1760 °F - Gas quenching
- -75 °C / -103 °F - 2 hrs
- Tempering 300 °C / 572 °F - 2 hrs

Typical aspect of the structure (carburized layer)

Comparison of hardness profiles

UNS: K51570
AMS 6494 (Air Melted), 6495 (Remelted)
FND

15NiMoSiCr10

MECHANICAL CHARACTERISTICS

Heat Treatment:

• **Gas quench** (3 bars) from 960 °C / 1760 °F. Sub-zero -75 °C / -103 °F. Temper at 300 °C / 572 °F

  Typical values:
  - UTS: 1350 MPa / 196 Ksi
  - 0.2 % YS: 1030 MPa / 149 Ksi
  - El: 13 %
  - KV: 110 J / 81 ft.lb

• **Oil quench** (3 bars) from 960 °C / 1760 °F. Sub-zero -75 °C / -103 °F. Temper at 300 °C / 572 °F

  Typical values:
  - UTS: 1400 MPa / 203 Ksi
  - 0.2 % YS: 1120 MPa / 162 Ksi
  - El: 13 %
  - KV: 120 J / 88 ft.lb

UNS: K51570
AMS 6494 (Air Melted), 6495 (Remelted)
**Rotative bending**

R = -1

Kt = 1.035

Fatigue limit for 2.10^7 cycles, 50% chance of failure

**Annealing:**
- 980 °C / 1796 °F - Air cooling
- 680 °C / 1266 °F - Air cooling

**Case hardening**

**Heat treatment to apply:**
- 960 °C / 1760 °F - Gas quenching
- -75 °C / -103 °C - 2 hrs
- Tempering 250 °C / 482 °F - 2 hrs

**Mechanical characteristics**

Heat treated material (base metal)
- UTS: 1378 MPa / 200 Ksi
- 0.2 % YS: 1014 MPa / 147 Ksi
- Fatigue limit 2.10^7 cycles: 729 MPa / 106 Ksi

Case hardened and heat treated material
- UTS: 1347 MPa / 195 Ksi
- 0.2 % YS: 989 MPa / 143 Ksi
- Fatigue limit 2.10^7 cycles: 1093 MPa / 158 Ksi

UNS: K51570
AMS 6494 (Air Melted), 6495 (Remelted)
Rotative bending fatigue S/n curve - case hardened

Rotative bending fatigue S/n curve – core material

UNS: K51570
AMS 6494 (Air Melted), 6495 (Remelted)
Comparison of the fatigue limit of different surface hardenable steels

Rotative bending
R = -1
Kt = 1.035
Fatigue limit for $2 \times 10^7$ cycles, 50% chance of failure

<table>
<thead>
<tr>
<th>A&amp;D Grades</th>
<th>Designations</th>
<th>Heat treatment</th>
<th>UTS (MPa / Ksi)</th>
<th>0.2% YS (MPa / Ksi)</th>
<th>Lf core (MPa / Ksi)</th>
<th>Lf case (MPa / Ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FADC (W)</td>
<td>10NiCrMo13-5</td>
<td>825°C / Oil -75°C 150°C</td>
<td>1150 / 467</td>
<td>900 / 131</td>
<td>600 / 97</td>
<td>1050 / 152</td>
</tr>
<tr>
<td></td>
<td>9310</td>
<td>1100°C / Oil -75°C 3 x 540°C</td>
<td>1400 / 203</td>
<td>1200 / 174</td>
<td>750 / 109</td>
<td>1075 / 156</td>
</tr>
<tr>
<td>50NLYW</td>
<td>13MoCrNiV42-16-14 M50N1L</td>
<td>825°C / Oil -75°C 150°C</td>
<td>1350 / 196</td>
<td>1000 / 145</td>
<td>760 / 110</td>
<td>1100 / 160</td>
</tr>
<tr>
<td>FADH (W)</td>
<td>14NiCrMo13-4 BS: S157 - 1.6657</td>
<td>825°C / Oil -75°C 150°C</td>
<td>1450 / 210</td>
<td>1100 / 160</td>
<td>890 / 129</td>
<td>1160 / 168</td>
</tr>
<tr>
<td>FDG (W)</td>
<td>20NiCrMo13 1.6660 AMS: 6492 - 6493</td>
<td>825°C / Oil -75°C 150°C</td>
<td>1350 / 196</td>
<td>1030 / 149</td>
<td>729 / 106</td>
<td>1093 / 158</td>
</tr>
<tr>
<td>FND (W)</td>
<td>15NiMoSiCr10 AMS: 6494 - 6495</td>
<td>960°C / Gas -75°C 250°C</td>
<td>1350 / 196</td>
<td>1030 / 149</td>
<td>729 / 106</td>
<td>1093 / 158</td>
</tr>
</tbody>
</table>

UNS: K51570
AMS 6494 (Air Melted), 6495 (Remelted)
FND

15NiMoSiCr10

JOMINY CURVE

The Jominy curves clearly show that FND is capable of large parts and displays homogeneous properties.