AD730®
NiCr16Co9Mo3W3Ti3Al2

New Ni-based Superalloy for High Temperature Applications
THE INDUSTRIAL ENVIRONMENT

The need to enhance the efficiency of aero engines has been driving force for development of new materials that combine high tensile strength, resistance to fatigue and creep with the capability to operate in the 700°C/750°C (1292°F/1382°F) temperature range.

In the same way, new power generation concepts, aiming at higher efficiency and reduced CO₂ emission, require novel alloys able to cope with adverse conditions associated with A-USC (Advanced Ultra Supercritical) operations. There again, advanced creep and fatigue properties, as well as microstructural stability at elevated temperatures are key.

Last but not least, the alloy’s hot working ability a significant aspect influencing the final cost-efficiency of the product.

AD730® has been developed to address these market challenges.

DEVELOPMENT OF AD730® ALLOY

AD730® is a fully-innovative cast & wrought nickel-based superalloy that withstands high temperatures (750°C/1382°F) while preserving strength, creep and fatigue resistance at a competitive cost.

The breakthrough mainly comes from the unique properties-versus-cost balance of AD730®, due to its recycling and forging ability.
AD730®

NiCr16Co9Mo3W3Ti3Al2

SPECIFICATIONS

NiCr16Co9Mo3W3Ti3Al2
AD730® patent is pending (EP2467505 / US20120183432)

INDUSTRIAL ROUTE

- VIM
- Remelting
- Ring rolling → rings
- Rolling → bars of small diameter
- Forging → billets, bars
- Closed-die forging → parts

APPLICATIONS

Aeroengine
Fasteners
Landbased turbine
Hot tooling

AD730® is a registered trademark of Aubert & Duval
**CHEMICAL COMPOSITION (weight %)**

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Fe</th>
<th>Cr</th>
<th>Co</th>
<th>Mo</th>
<th>W</th>
<th>Al</th>
<th>Ti</th>
<th>Nb</th>
<th>B</th>
<th>Zr</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini Base</td>
<td>3.6</td>
<td>15</td>
<td>8</td>
<td>2.5</td>
<td>2</td>
<td>2.0</td>
<td>3.3</td>
<td>0.8</td>
<td>0.005</td>
<td>0.01</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Maxi</td>
<td>5</td>
<td>17</td>
<td>10</td>
<td>3.5</td>
<td>3</td>
<td>2.5</td>
<td>3.9</td>
<td>1.4</td>
<td>0.02</td>
<td>0.05</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

- Solid solution strengthening of γ matrix by refractory elements (Mo and W)
- Reduced Co content compared to 720 Alloy
- Strengthening provided by γ’ phase
- High microstructural stability

The AD730® design minimizes expensive alloying elements to improve the cost/efficiency ratio: limited amounts of Co, Nb (Cb), Mo, W have been then targeted together with significant Fe content. The chemical composition has been optimized in order to reinforce the matrix for better hot tensile strength owing to the high substitution element content as shown above.

**ALLOY DESIGN**

The strengthening of AD730® was adjusted to obtain higher mechanical properties as compared to ATI718Plus® and Waspaloy. In comparison to 720 Alloy, γ’ amount was reduced to improve the ability for the cast & wrought route and solid solution strengthening was increased to counter-balance the decrease of γ’ fraction.
AD730®

NiCr16Co9Mo3W3Ti3Al2

PHYSICAL PROPERTIES

DENSITY

- 8.23 g/cm³

MEAN COEFFICIENT OF THERMAL EXPANSION*

<table>
<thead>
<tr>
<th>Temperature range from room temperature to indicated temperature</th>
<th>Mean coefficient of thermal expansion α</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
</tr>
<tr>
<td>600</td>
<td>316</td>
</tr>
<tr>
<td>800</td>
<td>427</td>
</tr>
<tr>
<td>1000</td>
<td>538</td>
</tr>
<tr>
<td>1200</td>
<td>649</td>
</tr>
<tr>
<td>1400</td>
<td>760</td>
</tr>
<tr>
<td>1600</td>
<td>871</td>
</tr>
</tbody>
</table>

YOUNG MODULUS*

![Young Modulus Graph]

Tested according to ASTM E1876-00 standard

*Sources: ONERA for AD730®; Literature – for other alloys

AD730® is a registered trademark of Aubert & Duval
ATI718Plus® is a registered trademark of ATI Properties, Inc.
AEREX®350 is a registered trademark of SPS Technologies
## THERMAL CONDUCTIVITY

### Mean data in SI units*

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>C Specific Heat (J/Kg.°C)</th>
<th>K Thermal conductivity (W/m.°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>485.8</td>
<td>11.26</td>
</tr>
<tr>
<td>100</td>
<td>497.9</td>
<td>12.02</td>
</tr>
<tr>
<td>200</td>
<td>515.0</td>
<td>13.13</td>
</tr>
<tr>
<td>400</td>
<td>526.4</td>
<td>15.35</td>
</tr>
<tr>
<td>500</td>
<td>549.6</td>
<td>17.79</td>
</tr>
<tr>
<td>600</td>
<td>573.0</td>
<td>20.39</td>
</tr>
<tr>
<td>700</td>
<td>603.7</td>
<td>21.99</td>
</tr>
<tr>
<td>800</td>
<td>634.4</td>
<td>23.63</td>
</tr>
<tr>
<td>900</td>
<td>663.4</td>
<td>25.58</td>
</tr>
</tbody>
</table>

### Mean data in U.S. units

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>C Specific Heat (Btu/lb.°F)</th>
<th>K Thermal conductivity (Btu-ft/ft²/hr/°F-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>90</td>
<td>6.5</td>
</tr>
<tr>
<td>212</td>
<td>93</td>
<td>6.9</td>
</tr>
<tr>
<td>392</td>
<td>96</td>
<td>7.6</td>
</tr>
<tr>
<td>752</td>
<td>98</td>
<td>8.9</td>
</tr>
<tr>
<td>932</td>
<td>102</td>
<td>10.3</td>
</tr>
<tr>
<td>1112</td>
<td>107</td>
<td>11.8</td>
</tr>
<tr>
<td>1292</td>
<td>112</td>
<td>12.7</td>
</tr>
<tr>
<td>1472</td>
<td>118</td>
<td>13.6</td>
</tr>
<tr>
<td>1652</td>
<td>123</td>
<td>14.8</td>
</tr>
</tbody>
</table>

*Source: ONERA

AD730® is a registered trademark of Aubert & Duval
MECHANICAL PROPERTIES: SUB-SOLVUS HEAT TREATMENT

- Sub-Solvus heat treatment:
  1070°C/1080°C (1958°F/1976°F) - 4h - Oil quenching + 730°C/760°C (1346°F/1400°F) - 8h - Air cooling

- Fine grain microstructure (average size finer than ASTM 7)
- Provides the best tensile strength / creep / fatigue resistance compromise.
- Strengthening provided by fine precipitation of γ’ precipitates into the grains

Grain size : G=10 ASTM

TENSILE PROPERTIES IN SUB-SOLVUS HEAT TREATMENT CONDITIONS

Typical values

<table>
<thead>
<tr>
<th>Temperature °C/°F</th>
<th>YS MPa/ksi</th>
<th>UTS MPa/ksi</th>
<th>EI (%)</th>
<th>Reduced Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 / 68</td>
<td>1235 / 179</td>
<td>1580 / 229</td>
<td>23</td>
<td>29</td>
</tr>
<tr>
<td>540 / 1004</td>
<td>1145 / 166</td>
<td>1540 / 224</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>600 / 1112</td>
<td>1130 / 164</td>
<td>1515 / 220</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>650 / 1202</td>
<td>1120 / 163</td>
<td>1375 / 200</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>700 / 1292</td>
<td>1105 / 160</td>
<td>1245 / 181</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>720 / 1328</td>
<td>1090 / 158</td>
<td>1180 / 171</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>750 / 1382</td>
<td>1050 / 152</td>
<td>1110 / 160</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>
**Tensile Properties in Sub-Solvus Heat Treatment Conditions**

In standard heat-treatment conditions AD730® shows:

- Tensile strength equivalent to 720 Alloy
- Superior tensile properties compared to 718 Alloy and ATI718Plus®
- Yield strength close to 1100 MPa (160Ksi) in the 650°C/730°C (1202°F/1346°F) temperature range

---

AD730® is a registered trademark of Aubert & Duval
ATI718Plus® is a registered trademark of ATI Properties, Inc.
Effect of Cooling Rate in Sub-Solvus Heat Treatment Conditions

Similarly to other superalloys strengthened by γ' phase, AD730® creep and tensile properties are sensitive to the cooling rate after solution heat-treatment. A high cooling rate promotes a fine intragranular γ' precipitation and a high strengthening effect.

A cooling rate higher than 70°C/min (158°F/min) is recommended to obtain the best combination of mechanical properties. Oil or polymer quenching may be performed after sub-solvus solution heat-treatment depending on the product size, to achieve the adequate cooling rate.

Influence of cooling rate on tensile strength at 700°C (1292°F)

Influence of Cooling rate on time to rupture at 700°C (1292°F) – 690 MPa (100 Ksi)

AD730® is a registered trademark of Aubert & Duval
**Creep Resistance in Sub-solvus Heat Treatment Conditions**

In standard heat-treatment conditions AD730® shows creep strength comparable to that of 720 Alloy and significantly higher than those of 718 and ATI718Plus® alloys. Compared to 718 Alloy, the improvement of creep temperature capability is close to 50°C (122°F).

![Creep Resistance Graph](image)

**Fatigue Resistance in Sub-solvus Heat Treatment Conditions**

Constant strain amplitude fatigue tests at 550°C (1022°F) have been carried out in sub-solvus heat-treatment conditions. AD730® alloy shows good fatigue resistance in this fine grains condition:

![Fatigue Resistance Graph](image)

**Notes**: Direct Aged 718 fatigue literature. Data sources: Krueger, Superalloy 718: Metallurgy and Applications, Edited by E.A. Loria. The Minerals, Metals & Materials Society, 1989; p279. AD730® is a registered trademark of Aubert & Duval. ATI718Plus® is a registered trademark of ATI Properties, Inc.
In standard heat-treatment conditions, fatigue properties of AD730® are similar to those of Direct Aged 718 Alloy which is an upgraded version of 718 Alloy in terms of tensile and fatigue resistance.

**Fatigue crack growth rate with hold time in sub-solvus heat treatment conditions**

In standard heat-treatment conditions, AD730® shows dwell fatigue crack growth resistance:

- better than 718 Alloy
- comparable to 720 Alloy
AD730® was designed to have microstructural stability higher than 718 Alloy, ATI718Plus®, Waspaloy and 720 Alloy.

No topologically close-packed (TCP) phases detected after overageing between 800°C and 900°C (1472°F and 1652°F) after Scanning Electron Microscopy (SEM) examinations.
AD730® is a registered trademark of Aubert & Duval
ATI718Plus® is a registered trademark of ATI Properties, Inc.

AD730® shows remarkable microstructure stability in the 700°C/900°C (1292°F/1652°F) temperature range, even after several thousands of hours of temperature holding time. Microstructural stability was assessed after a long-term aging of 3000 hours at 750°C (1382°F) performed after the conventional sub-solvus heat-treatment.

Mechanical tests, performed before and after this long-term aging, show that:
- AD730® can be used up to 750°C (1382°F).
- No topological close-packed (TCP) embrittlement phase was observed.
- Strength decrease is less significant than that of 718 Alloy, ATI718Plus® and Waspaloy.

Before long term aging

After long term aging

Impact strength (20°C/68°F) = 31J
UTS (650°C/1202°F) = 1368 MPa / 199 Ksi
YS (650°C/1202°F) = 1088 MPa / 158 Ksi
EI (650°C/1202°F) = 28%

Impact strength (20°C/68°F) = 30J
UTS (650°C/1202°F) = 1257 MPa / 182 Ksi
YS (650°C/1202°F) = 1024 MPa / 149 Ksi
EI (650°C/1202°F) = 40%
MECHANICAL PROPERTIES: SUPER-SOLVUS HEAT TREATMENT

Double step solution heat treatment:

- 1120°C - 4h - Air cooling + 1080°C - 4h - cooling rate(>100°C/min - 212°F/min)
  + 800°C (1472°F) - 4h - Air cooling + 760°C (1400°F) - 16h - Air cooling

- Double step aging 800°C/850°C (1472°F/1562°F)-4h - Air cooling + 760°C (1400°F)-16h - Air cooling

- Coarse grain microstructure (Average grain size into the range ASTM 0 to 4)

- Enhanced creep resistance and fatigue crack growth resistance
**AD730®**

**NiCr16Co9Mo3W3Ti3Al2**

---

**Tensile strength in super-solvus heat treatment conditions**

In coarse grains condition (super-solvus HT), AD730® has higher tensile strength than Waspaloy. Yield strength remains higher than 900 MPa (131 Ksi) in temperature range 20°C/750°C (68°F/1382°F).

---

*AD730® Tensile stress after super-solvus heat treatment*

*Yield strength after super-solvus heat treatment*

*Ultimate tensile strength after super-solvus heat treatment*
AD730®

Creep strength in super-solvus heat treatment conditions
- Better creep resistance than Waspaloy

Fatigue crack growth rate in super-solvus heat treatment conditions
- In super-solvus heat-treated conditions AD730® presents a dwell time fatigue crack growth resistance that is improved compared to the standard condition.
HOT FORGING ABILITY

Tensile tests at elevated temperature and high strain rate (10-1 s⁻¹) show much better hot forging ability for AD730® alloy compared to Waspaloy and 720 Alloy. AD730® can be forged below γ′ solvus allowing fine grain size which is not possible for Waspaloy.

Forging is normally done below the γ′ solvus temperature in the 1050°C/1922°F temperature range to prevent grain growth. However, the forging temperature should be ≥ 930°C (1706°F). Bars and billets in AD730® are easier to forge than those in Waspaloy or 720 Alloy. The forging process allows a good control of final microstructure.

HOT CONVERSION PROCESSES OF AD730®

Forged bar  Rolled bar  Closed-die forged part  Rolled ring
OXIDATION

Oxidation in dry air has been studied using thermo-gravimetry devices. The mass change has been recorded continuously for AD730®, Waspaloy and 720 Alloy. A better behavior of AD730® is observed under test conditions as shown in the figure below.

Micrographic examinations of the oxide scale after 200-hour exposure show the growth of a protective oxide scale for AD730® with a rather limited intergranular oxidation. On the contrary, 720 Alloy and Waspaloy show a pronounced intergranular oxidation (see figures below).

AD730®

NiCr16Co9Mo3W3Ti3Al2

AD730® is a registered trademark of Aubert & Duval
AD730®

NiCr16Co9Mo3W3Ti3Al2

MACHINABILITY

Machinability of AD730® is similar to that of other refractory nickel base superalloys.

- Rigid machine and tooling are required
- Ceramic tools can be used for rough machining
- Coated and uncoated carbides can be used for finish machining operations
- Positive cuts should be applied at all times to avoid excessive work hardening of material

WELDABILITY

Due to the high percentage of $\gamma'$, inertia is a recommended welding process for AD730® grade.
AD730®
NiCr16Co9Mo3W3Ti3Al2

TARGET APPLICATIONS

AERO ENGINE COMPONENTS

The latest designs of high-efficiency engines have high requirements for the mechanical properties and temperature capability of the key components, especially the stages of disks where the stress and temperature are the highest. Alloy development for turbine disks with higher properties and temperature capability is consequently crucial in order to improve the thermal efficiency in gas turbine engines.

AD730® alloy was designed to propose an original cost-effective alloy for aero engine applications with similar mechanical properties to those of 720 Alloy for a lower cost.

High Pressure turbine disk
Safran Helicopter Engines
AD730®

**LAND BASED TURBINES**

The increasing requirements for higher service temperatures together with high cyclic loads make alloy AD730® a preferred choice for land-based turbine applications such as turbines blades, seals, fasteners, and high pressure gas turbine discs. AD730® withstands higher temperatures (750°C / 1382°F) while preserving strength, creep and fatigue resistance.

- Blades can be manufactured either by machining from annealed rectangular bars or by forging from billet. In case of forging from billet, a sub-solvus forging temperature should be applied as fine grain size is usually required for these applications. In both processes a complete sub-solvus annealing and aging heat treatment is required. Sufficient allowances should be left to cope with possible heat treatment deformation.

- Initially designed for aero-engine applications, AD730® is an alternative to 720 and 718 alloys and to Waspaloy used in hot sections of land-based turbines. Depending on customer specification requirements, sub-solvus or super-solvus heat treatment conditions are applied.

**FASTENERS**

The unique tensile strength / creep resistance combination of AD730® makes the grade suitable for fasteners and nuts for service temperature range 650°C/750°C (1202°F/1382°F).

- Fasteners can be manufactured via a full machining process from bars delivered in annealed condition for better machining conditions. After pre-machining a complete sub-solvus heat treatment is applied for mechanical properties.

- Should the bolt heads be manufactured by forging, the forging temperature has to be in the 1070°C/1090°C (1958°F/1994°F) range to prevent increase of grain size. After forging a new annealing treatment is recommended for further machining before final ageing heat treatment.

- AD730® material has been shown to be sensitive in specific conditions to notch embrittlement for stress concentration factors above Kt=3.7. Hence lower values of Kt are recommended for bolt and nut designs. For the highest values of Kt, higher ageing temperatures and slower cooling rates after solution heat-treatment are recommended: ageing at 760°C (1400°F) for 8 hours gives satisfying behavior for the material with a good compromise between tensile strength, creep resistance and crack propagation rates.
AD730®
NiCr16Co9Mo3W3Ti3Al2

REFERENCES

ALLOY DESIGN

PROCESS AND INDUSTRIALIZATION
C. Crozet et al., Effect of ingot size on microstructure and properties of the new advanced AD730 superalloy, Superalloys 2016, TMS, 2016, pp 437-446

HEAT-TREATMENT STUDIES
A. Devaux et al., Mechanical properties and development of supersolvus heat treated new nickel base superalloy AD730™, MATEC Web of Conferences 14, 01004 (2014) (Eurosuperalloys 2014)
A. Devaux et al., Effect of aging heat-treatment on mechanical properties of AD730™ superalloy, 8th International Symposium on Superalloy 718 and Derivatives, TMS (The Minerals, Metals & Materials Society), 2014, pp 485-499

METALLURGICAL INVESTIGATIONS
C. Bellot, P. Lamesle, Quantitative measurement of γ' precipitates in two industrial nickel-based superalloys using extraction and high resolution SEM imaging, Journal of Alloys and Compounds 570 (2013)100-103
F. Masoumi et al., Kinetics and Mechanisms of γ' Reprecipitation in a Ni-based Superalloy, Scientific Reports 6, Article number: 28650 (2016)

MECHANICAL BEHAVIOR
L. Thebaut et al., Relationships between Microstructural Parameters and Time-Dependent Mechanical Properties of a New Nickel-Based Superalloy AD730™, Metals 2015, pp 5, 2236-2251
A. Devaux et al., Evaluation of AD730™ for high temperature fastener applications, Superalloys 2016, TMS, 2016, pp 469-478
L. Thebaut et al., Relationships between microstructural parameters and time-dependent mechanical properties of a new nickel based superalloy AD730™, Superalloys 2016, TMS, 2016, pp 877-896

AD730® is a registered trademark of Aubert & Duval
The information and the data presented herein are typical or average values and are not a guarantee of maximum or minimum values. Applications specifically suggested for material described herein are made solely for the purpose of illustration to enable the reader to make his own evaluation and are not intended as warranties, either express or implied, of fitness for those or other purposes.

Aubert & Duval’s liability shall not extend, under any circumstances, to the choice of the Product and its consequences.

Design: © Aubert & Duval 06/2017