AD730®

NiCr16Co9Mo3W3Ti3Al2

Ni-based Superalloy for High Temperature Applications

AUBERT&DUVAL

> 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.

> SPECIFICATIONS

NiCr16Co9Mo3W3Ti3Al2

AD730® patent is pending (EP2467505 / US20120183432)

> INDUSTRIAL ROUTE

VIM

REMELTING: FORGING, BILLETS, BARS

RING ROLLING: RINGS

ROLLING: BARS

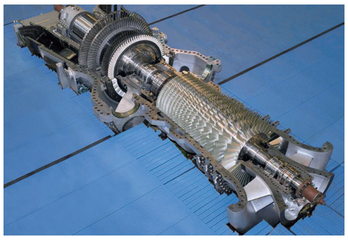
FORGING: BILLETS, BARS

CLOSED-DIE FORGING: PARTS

> APPLICATIONS

Aeroengines (disks, seals, casings)

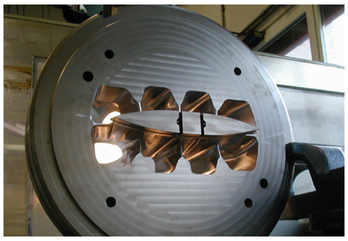
Space



Land turbines

Motorsport

Missiles



Hot tooling

> CHEMICAL COMPOSITION (weight %)

	Ni	Fe	Cr	Co	Mo	W	Al	Ti	Nb	B	Zr	C
Mini	Base	3.6	15	8	2.5	2	2.0	3.3	0.8	0.005	0.01	-
Maxi		5	17	10	3.5	3	2.5	3.9	1.4	0.02	0.05	0.02

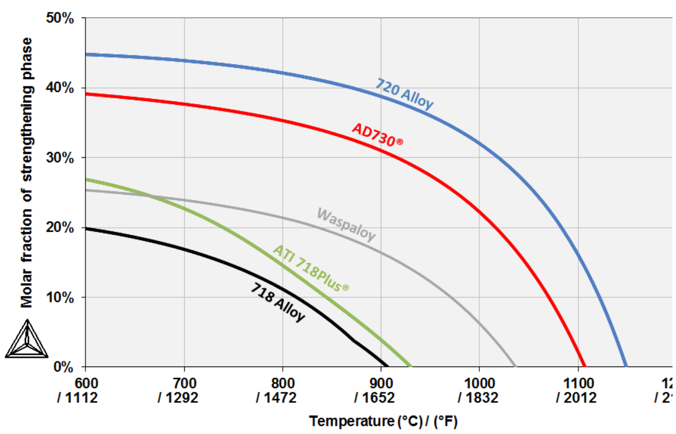
- Solid solution strengthening of γ matrix by refractory elements (Mo and W)
- Reduced Co content compared to 720 Alloy
- Strengthening provided by γ' phase
- High microstrutural stability

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.

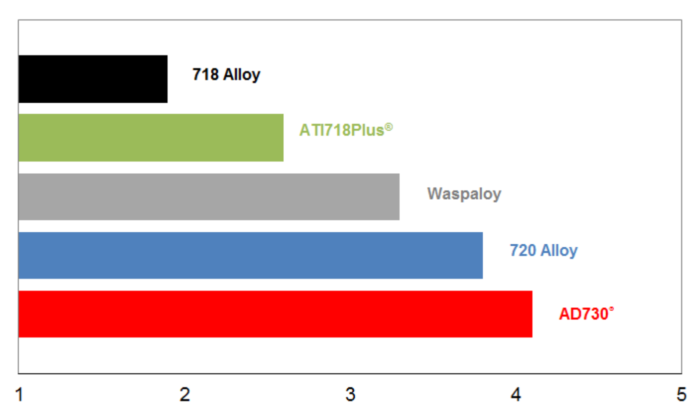
The chemical composition has been optimized in order to reinforce the matrix for better hot tensile strength owing to the high substitution element content as shown above.

> 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.



Calculated molar fraction of strengthening phase (γ' and/or γ'') versus temperature for various cast & wrought superalloys.



Calculated amount of refractory element (Mo + W) in solution into γ matrix at 700°C (1292°F) for various cast & wrought superalloys.

(Calculations realized with Thermocalc software with Thermotech Ni-based superalloys database)

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ATI718Plus® is a registered trademark of ATI Properties, Inc.

> PHYSICAL PROPERTIES

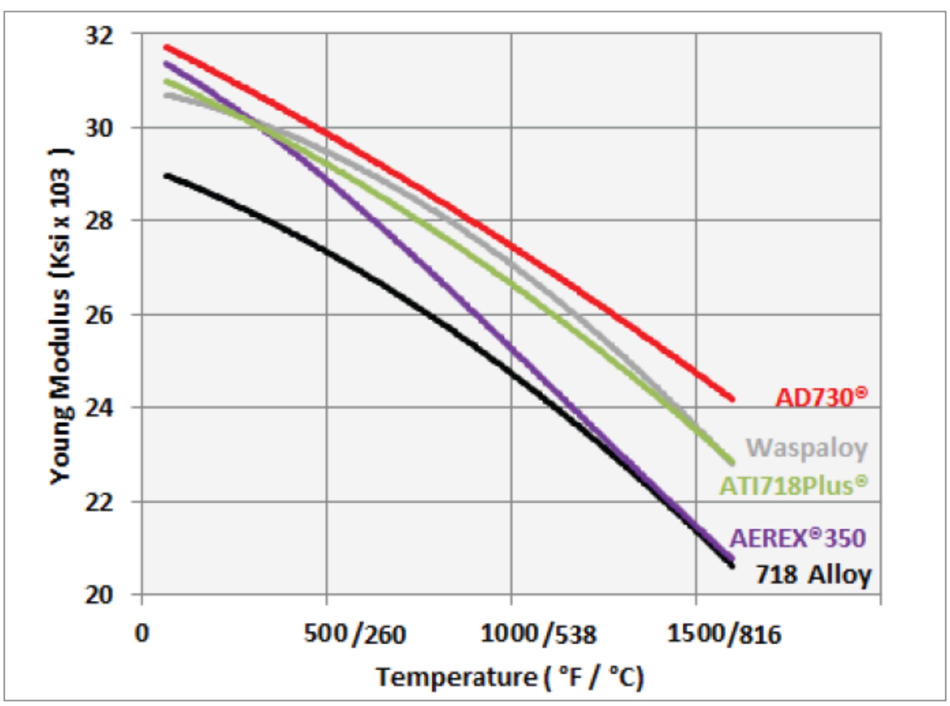
Density

- 8.23g/mm²

Mean coefficient of thermal expansion*

Temperature range from room temperature to indicated temperature 10 -6.m /m.°C		Mean coefficient of thermal expansion α	
°C	°F	10-6 m/m/°C	10-6 Inch/Inch/°F
600	316	12.8	7.1
800	427	13.4	7.4
1000	538	14.0	7.8
1200	649	14.8	8.2
1400	760	15.4	8.6
1600	871	16.4	9.1

Young modulus*



Tested according to ASTM E1876-00 standard

Temperature	GPA
20°C, 68°F	219
200°C, 392°F	189
500°C, 932°F	179

*Sources : ONERA for AD730®; Literature – for other alloys
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AEREX®350 is a registered trademark of SPS Technologies

> THERMAL CONDUCTIVITY

Mean data in SI units*

Temperature (°C)	C Specific Heat (J/Kg.°C)	K Thermal conductivity (W/m.°C)
300	485.8	11.26
100	497.9	12.02
200	515.0	13.13
400	526.4	15.35
500	549.6	17.79
600	573.0	20.39
700	603.7	21.99
800	634.4	23.63
900	663.4	25.58

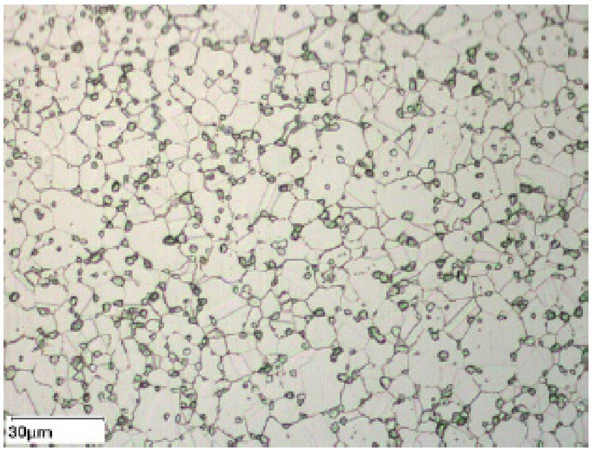
Mean data in US units*

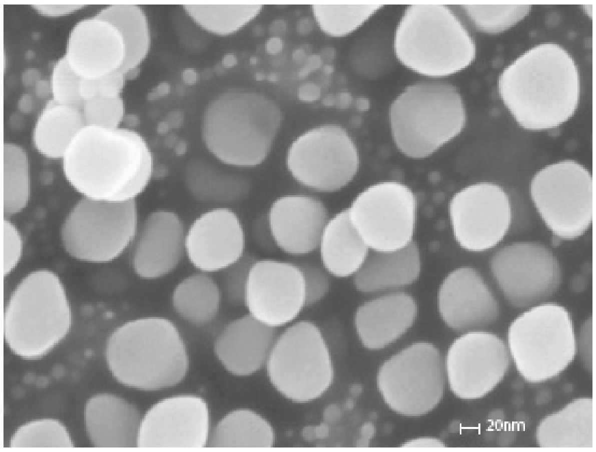
Temperature (°F)	C Specific Heat (Btu/lb.°F)	K Thermal conductivity ((Btu-ft/ft2/h/°F-1)
86	90	6.5
212	93	6.9
392	96	7.6
752	98	8.9
932	102	10.3
1112	107	11.8
1292	112	12.7
1472	118	13.6
1652	123	14.8

**Source: ONERA*

> MECHANICAL PROPERTIES: SUB-SOLVUS HEAT TREATMENT

- Sub-Solvus heat treatment:
1060°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

Temperature °C /°F	*YS MPa / ksi*	*UTS MPa / ksi*	*El (%)*	*Reduced Area (%)*
20/68	1220/178	1580/229	23	29
540/1004	1145/166	1540/224	20	26
600/1112	1130/164	1515/220	20	23
650/1202	1120/163	1375/200	19	20
700/1292	1105/160	1245/181	14	18
720/1328	1090/158	1180/171	12	16
750/1382	1050/152	1110/160	10	15

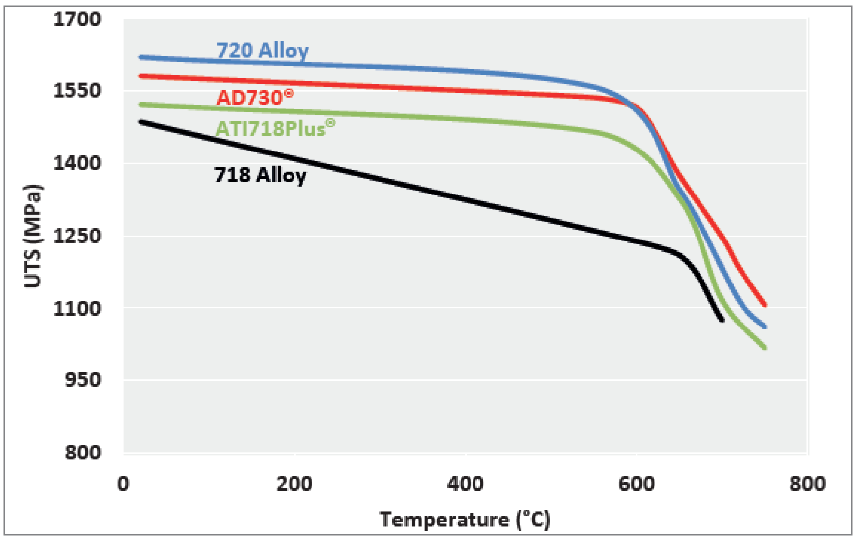
Tensile properties in sub-solvus heat treatment conditions

In standard heat-treatment conditions AD730® shows:

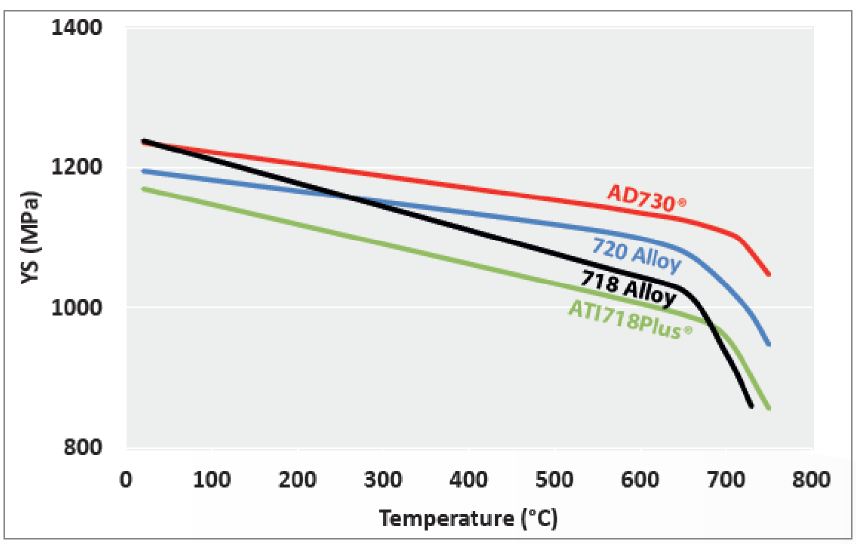
Tensile strength equivalent to 720 Alloy

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



Tensile properties (Ultimate Tensile Strength)



Tensile properties (Yield Strength)

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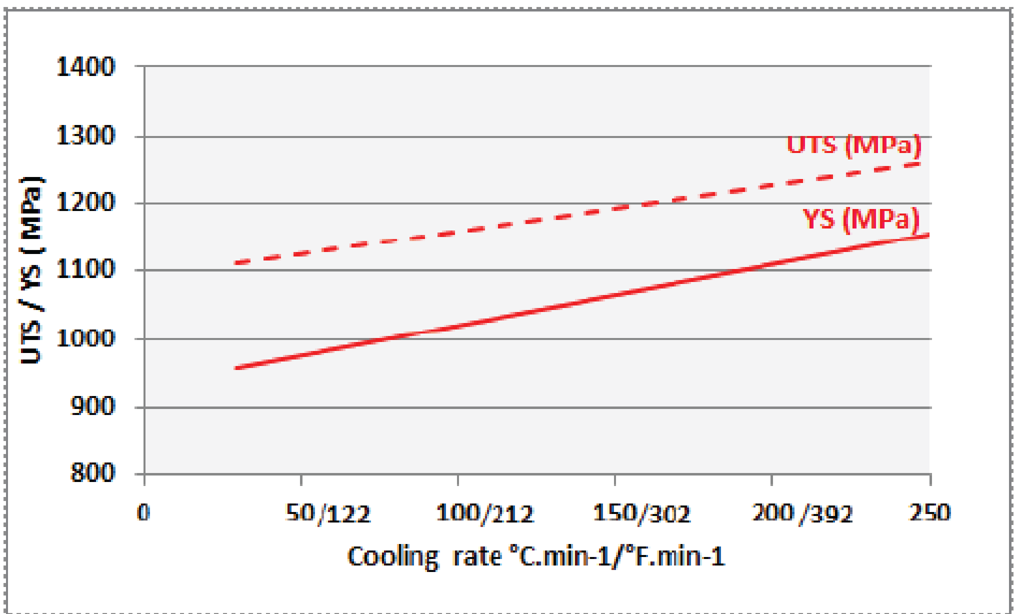
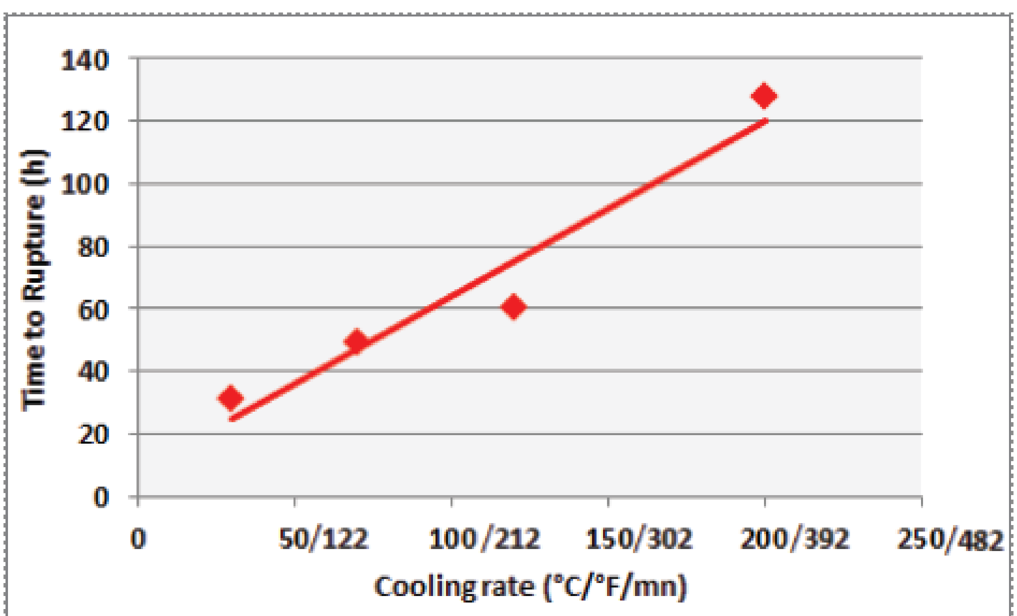
EFFECT OF COOLING RATE IN SUB-SOLVUS HEAT TREATMENT CONDITIONS

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 perfored 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)

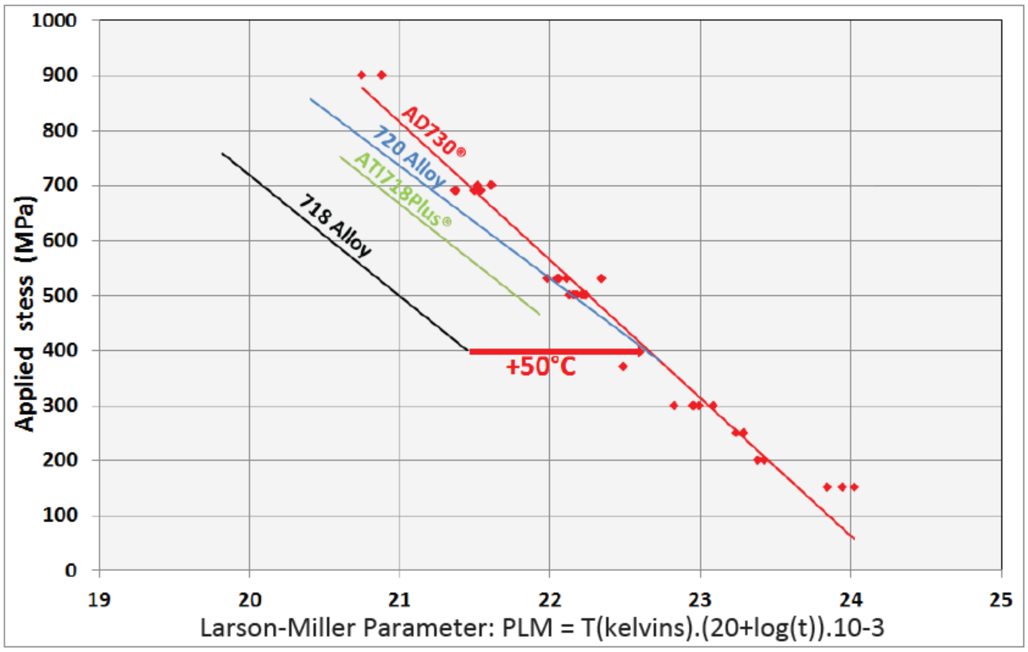


Influence of Cooling rate on time to rupture at 700°C (1292°F) - 690 MPa (100 Ksi)

Creep resistance in sub-solvus heat treatment conditions

In standard heat-treatment conditions AD730® shows:

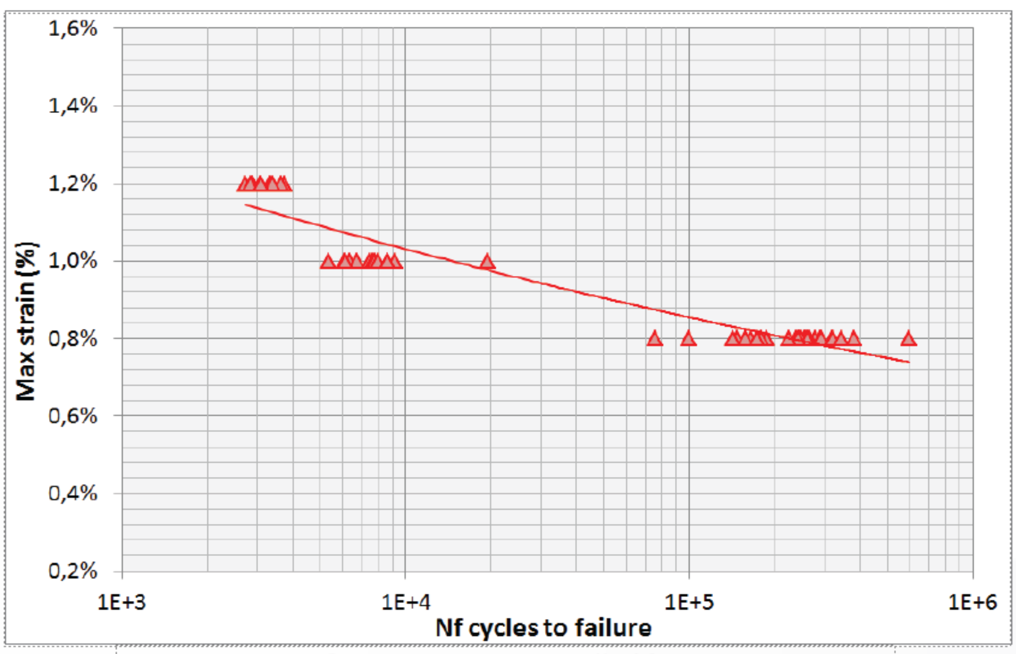
- Creep strength comparable to that of 720 Alloy and significantly higher than those of 718 and ATI718Plus® alloys.
- Compared to 718 Alloy, the improvement of creep temperature capability is close to 50°C (122°F).



Sub-solvus heat-treatment: Stress rupture tests

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:



AD730® fine grain strain controlled fatigue tests
Test temperature 550°C (1022°F);
R=0,1; 0,6% < εmax < 1,2%; Sinusoidal wave - Frequency=0,5 Hz

Direct Aged 718 fatigue litterature Data sources:
Krueger, Superalloy 718-Metallurgy and Applications, Edited by E.A. Loria
The Minerals, Metals & Materials Society, 1989, p279
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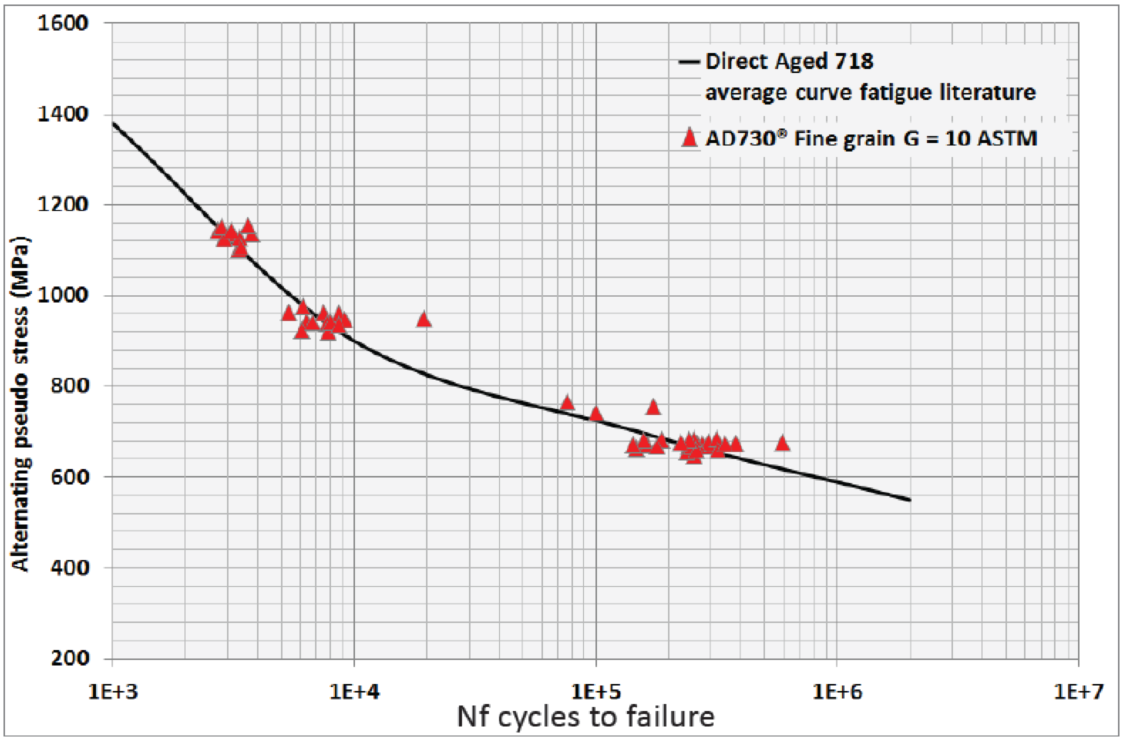
In standard heat-treatment conditions fatigue properties of AD730® are similar to those of Direct Aged 718 Alloy which is an upgraded version of 718 Alloy in terms of tensile and fatigue resistance.



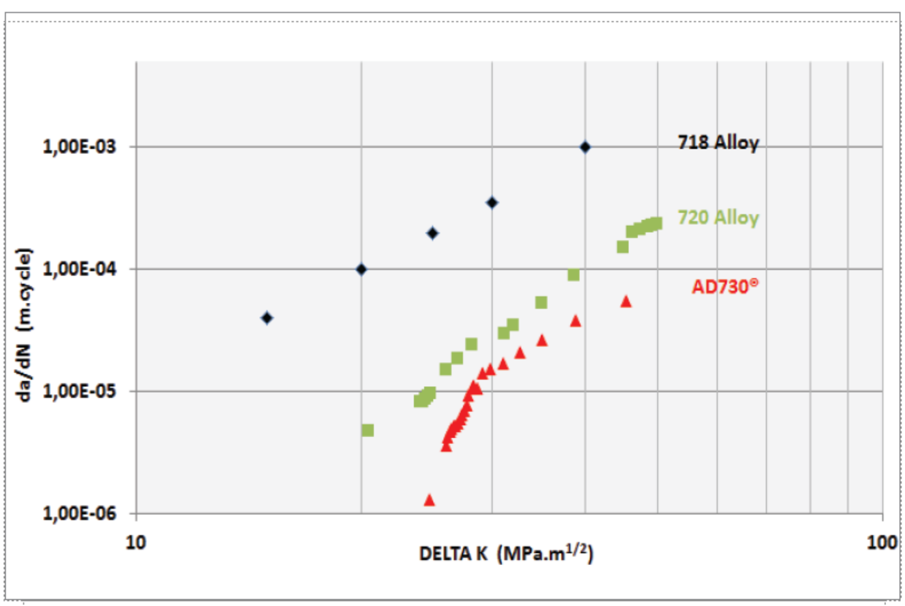
Fatigue resistance

Test temperature 550°C (1022°F); R=0,1; Sinusoidal wave - Frequency=0,5 Hz

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 heat-treatment



Crack growth rates of various C&W alloys

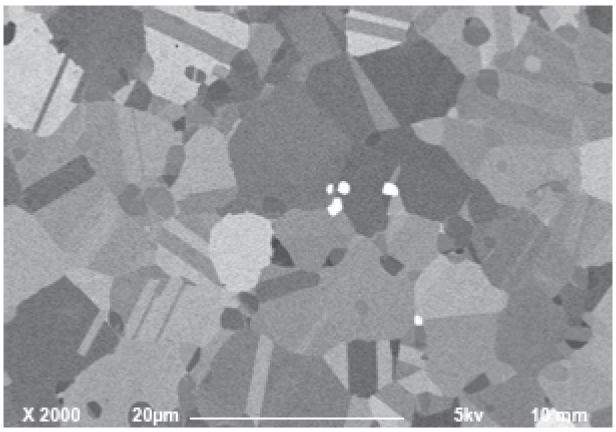
Temperature 650°C (1202°F); Stress Load Ratio R=0.1;

Trapezoidal wave form with 300 seconds at the peak load (10s-300s-10s)

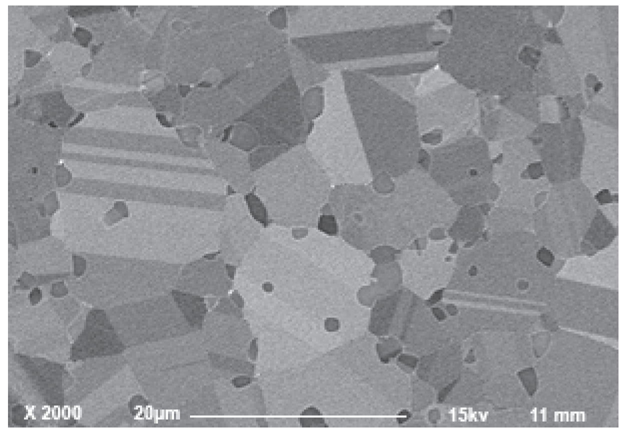
> MICROSTRUCTURE STABILITY AT ELEVATED TEMPERATURE

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

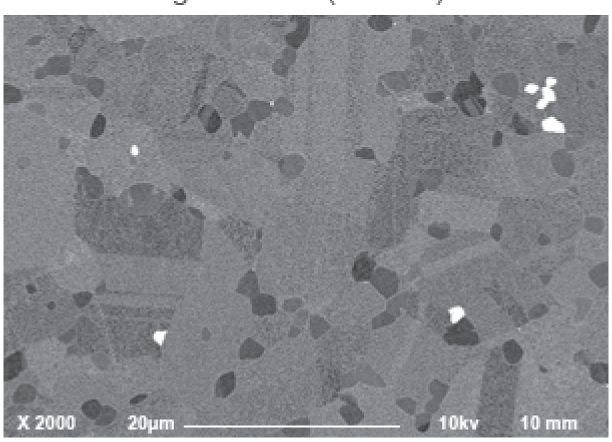
Initial



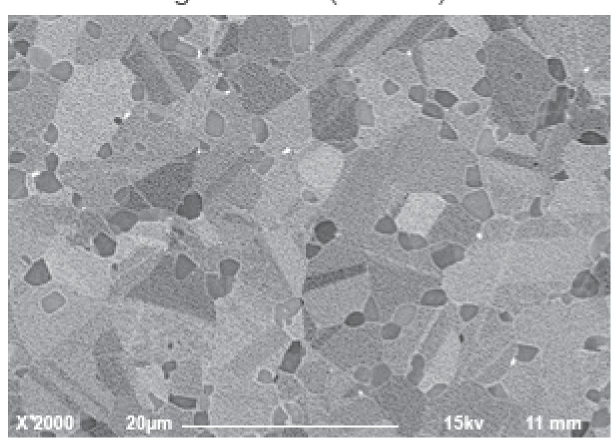
Overaged 800°C (1472°F)/500h



Overaged 850°C (1562°F)/500h



Overaged 900°C (1652°F)/100h



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.

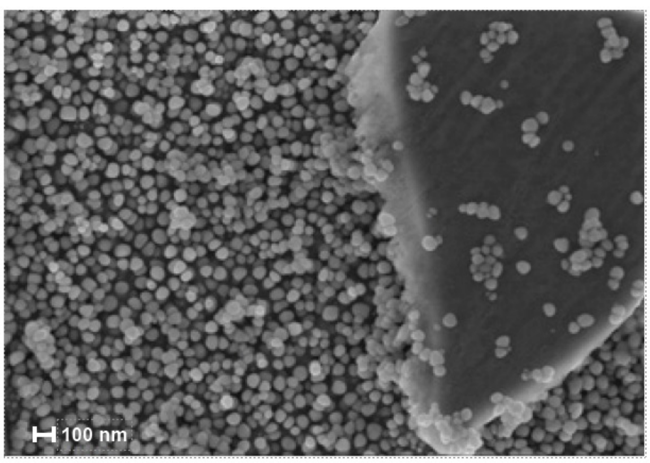
Source: ONERA
ATI718Plus® is a registered trademark of ATI Properties, Inc.

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 heattreatment.

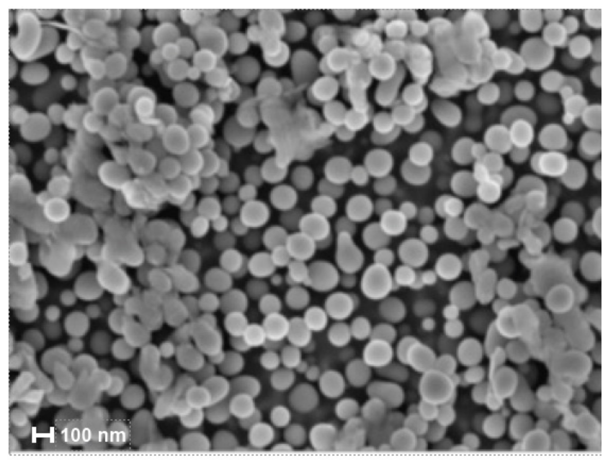
Mechanical tests, performed before and after this long-term aging, show that:

- 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



Before long term aging		After long term aging
Impact strength (20°C/68°F) = 31J	= Equal	*Impact strength (20°C/68°F) = 30J*
UTS (650°C/1202°F) = 1368 MPa / 199 Ksi	-8%	*UTS (650°C / 1202°F) = 1257 MPa / 182 Ksi*
YS (650°C/1202°F) = 1088 MPa / 158 Ksi	-6%	*YS (650°C / 1202°F) = 1024MPa / 149 Ksi*
El (650°C/1202°F) = 28%	+40%	*El (650°C / 1202°F) = 40%*

> MECHANICAL PROPERTIES: SUPER-SOLVUS HEAT TREATMENT

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

Double step solution heat treatment:

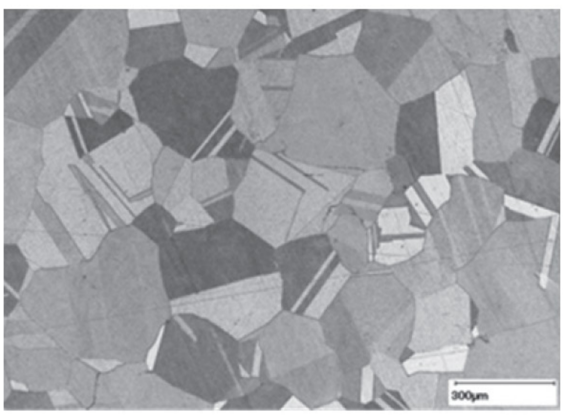
· 1120°C - 4h - Air cooling + 1080°C - 4h - cooling rate(>100°C/min - 212°F/min)

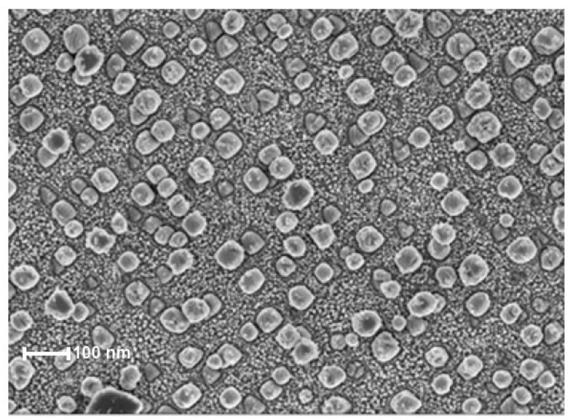
+ 800°C (1472°F) - 4h - Air cooling + 760°C (1400°C) - 16h - Air cooling

· 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



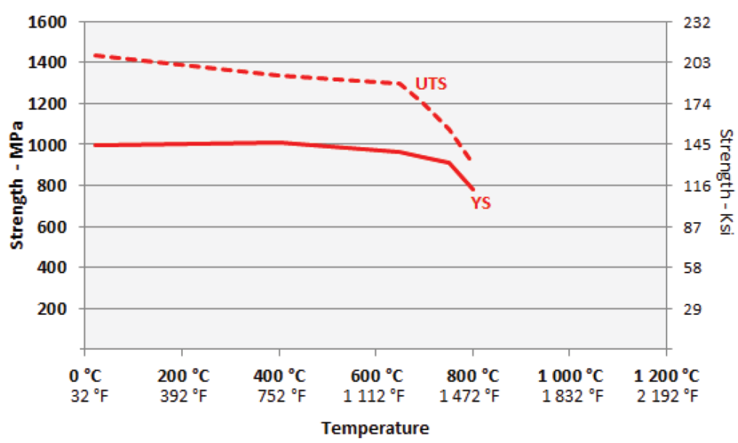


Grain size: G = 2 ASTM

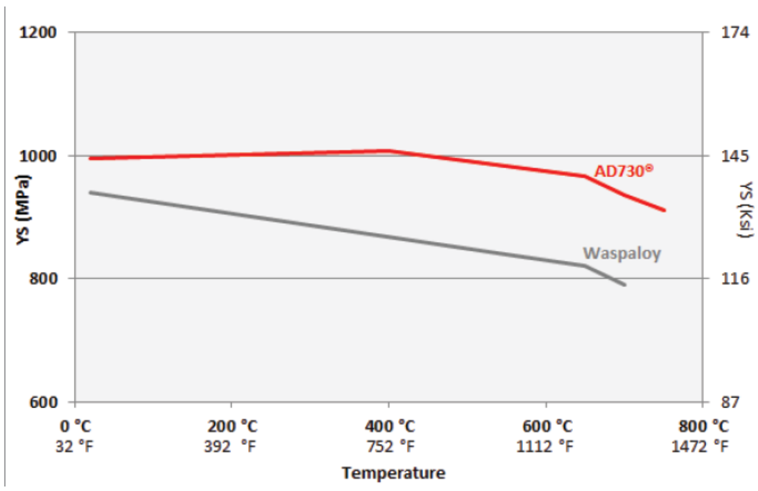
Tensile strength in super-solvus heat treatment conditions

In coarse grains condition (super-solvus HT), AD730® has higher tensile strength than Waspaloy.

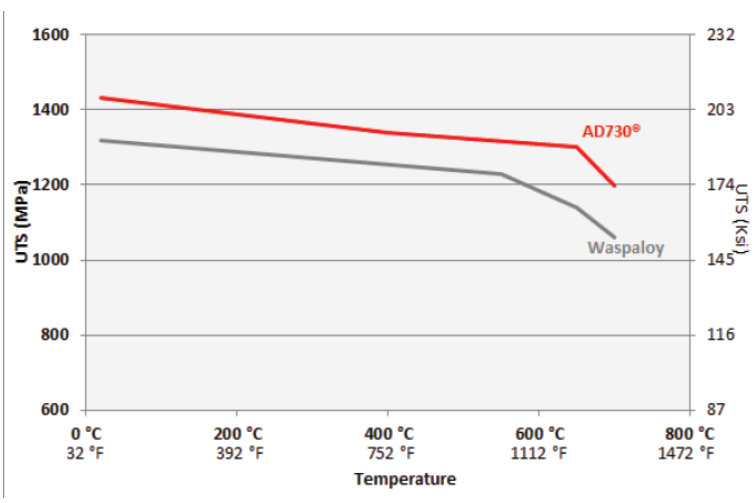
Yield strength remains higher than 900 MPa (131 Ksi) in temperature range 20°C-750°C (68°F-1382°F).



AD730® Yensile stress after super-solvus heat treatment



Yield strength after super-solvus heat treatment



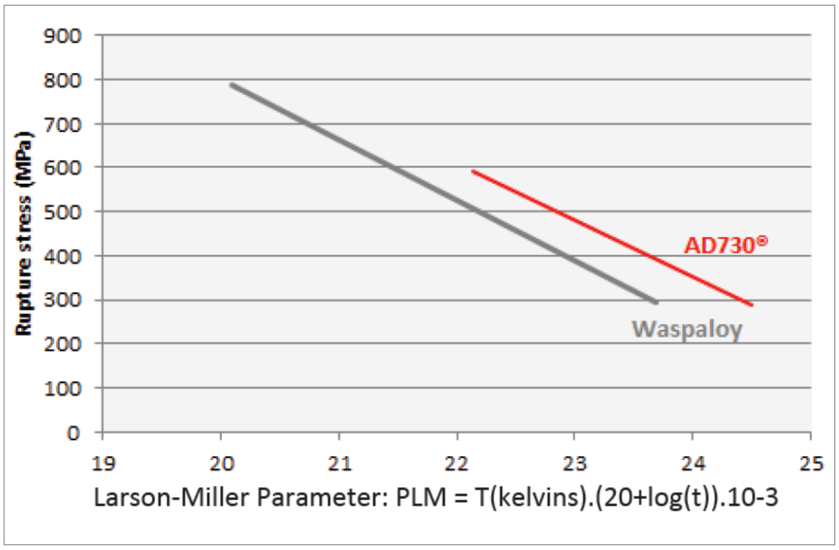
Ultimate tensile strength after super-solvus heat treatment

Creep 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).

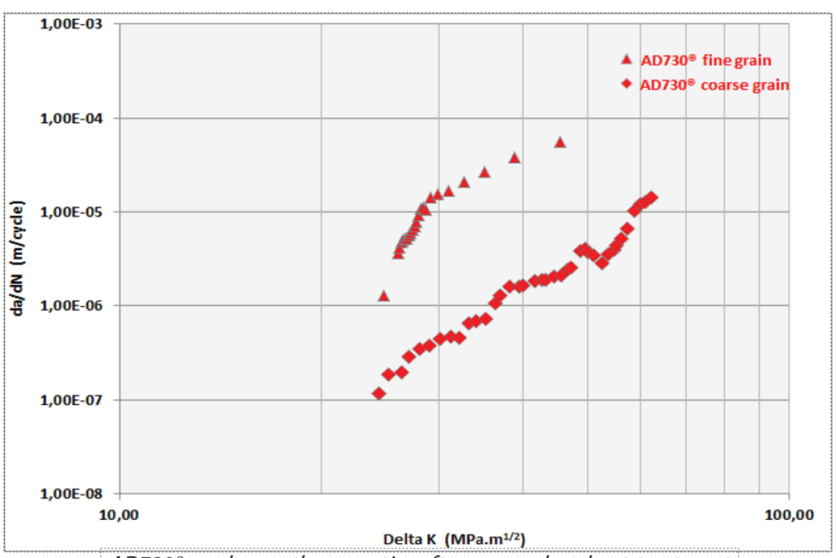
- Better creep resistance than Waspaloy



Stress rupture tests

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.



AD730® crack growth properties after supersolvus heat-treatment 650°C (1202°F), R=0,1, 10s-300s-10s) da/dN (m/cyc)

> 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.

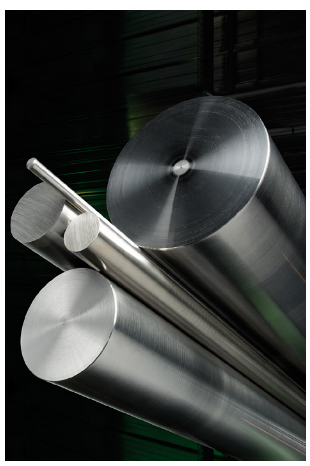
AD730® can be forged below γ' solvus allowing fine grain size which is not possible for Waspaloy.

Forging is normally done below the γ' solvus temperature in the 1050°C-1090°C (1922°F-1994°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®

Forging



Rolling

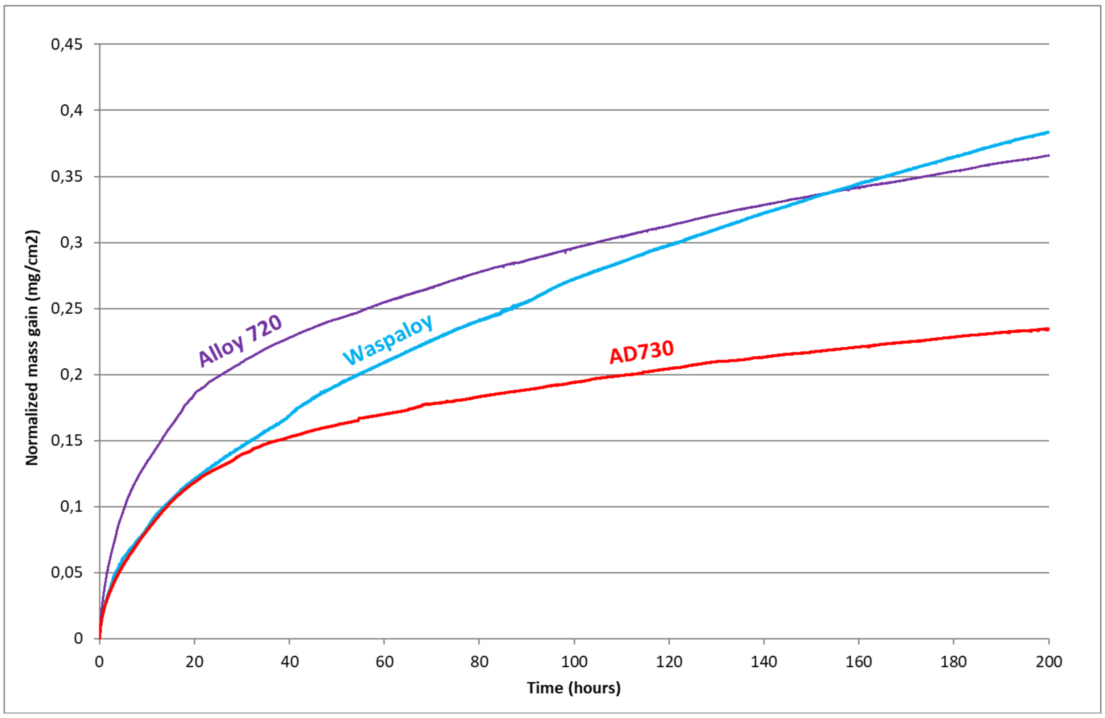
Closed-die forging

Ring rolling

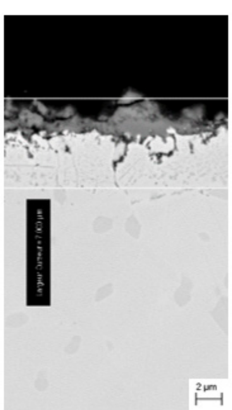
> OXIDATION

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

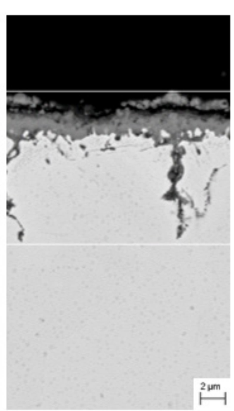
conditions as shown in the figure below.



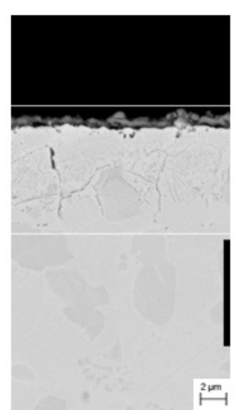
Micrographic examinations of the oxide scale after 200-hour exposure show the growth of a protective oxide scale for AD730® with a rather limited intergranular oxidation. On the contrary, 720 Alloy and Waspaloy show a pronounced intergranular oxidation (see figures below).



AD730®



Waspaloy



Alloy 720

> MACHINABILITY

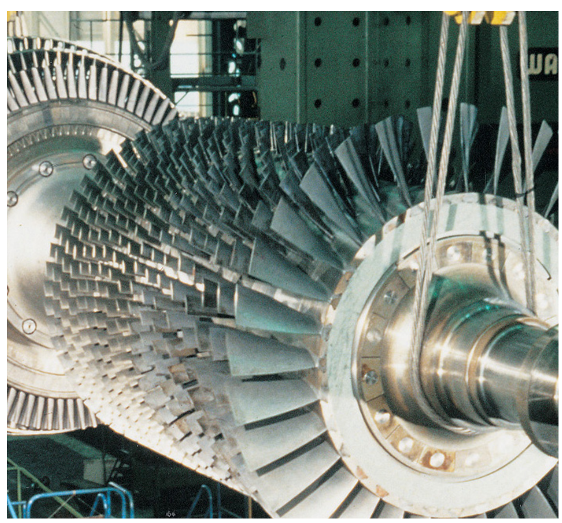
Machinability of AD730® is similar to that of other refractory nickel base superalloys.

- 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

AD730® is weldable by linear friction and tungsten inert gas techniques.

Welding trials of new Aubert & Duval nickel alloy, AD730® - TWI (twi-global.com)



> 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

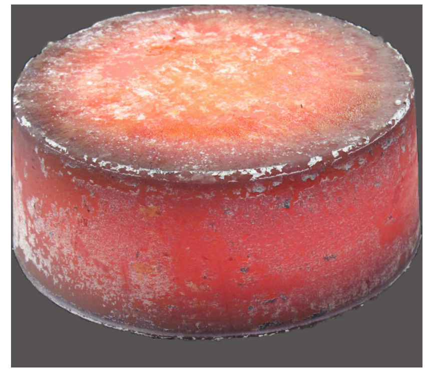
LAND BASED TURBINES

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.



AD730® as forged disc for gas turbine

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.

In case 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.

Fasteners

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