

AUBERT&DUVAL



XD16NTM

X50CrSiMnVN16-1

**A new martensitic stainless steel
for corrosion, temperature
and wear resistance**

**CONTINUOUS
METALLURGICAL
INNOVATION**

SPECIAL STEELS

DEVELOPMENT

RESEARCH

SERVICE

Enhancing your performance

XD16N

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THE INDUSTRIAL ENVIRONMENT

Numerous applications require the use of stainless steels resisting high mechanical stresses combined with abrasive and corrosive environments.

Besides some of these applications work at relatively high temperature.

For industrial bearings, ball-screws and for certain tools, the required hardness (56 – 58 HRC min) combined with the need for hard carbides for wear resistance strongly limits the material choice.

A very common grade used is AISI 440C / X105CrMo17 (XDBD), and associated compositions. Addition of W, V and Nb can be made to improve the temperature resistance. However, for all these grades, it is the carbon content that gives the required hardness and it has to be kept at a minimum of 0.7% to yield 58 HRC.

For valve applications, commonly used solutions are 1.4748 – X85CrMoV18-2 (APZ9) with high sensitivity to quench cracking or 1.4718 – X45CrSi9-3 (SOS3) with very poor corrosion resistance.

Such high carbon content has the following consequences:

- Coarse carbide structures
- Localized Cr depletion around large carbides
- High sensitivity to tempering due to carbide precipitation

...leading to well-documented limitations:

- Limited corrosion resistance
- Very limited corrosion resistance at high tempering temperatures
- Limited fatigue resistance
- Sensitivity to carbide pull-out
- Polishing difficulties

DEVELOPMENT OF XD16N

The following criteria have been taken into account during the design of this grade, initially developed for industrial bearings and induction hardened ball-screws:

- Good resistance to temperature
- Good toughness combined with high hardness, typically 58 HRC
- Good fatigue properties
- Low retained austenite compared to AISI 440C after heat treatment in order to ensure a high dimensional stability of the parts

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CHARACTERISTICS OF THE GRADE

Partial substitution of carbon with nitrogen, limited in order to ensure the fabrication of air melted products. The combination of nitrogen and carbon ensures:

- The formation of fine eutectic carbides
- A minimum hardness of 58 HRC

Nitrogen combined with chromium and molybdenum plays a favourable role in pitting corrosion resistance.

Molybdenum and vanadium ensure a secondary hardening.

Silicon, molybdenum and vanadium ensure temperature resistance.

APPLICATIONS

- Bearings, ball-screws for industrial applications, gears
- Valves
- Injection systems for automotive
- Cold work in corrosive environment

CHEMICAL COMPOSITION

	C	Si	Mn	Cr	Mo	V	N	Ni
min.	0.45	1.30	--	15.00	0.20	0.20	0.05	--
max.	0.60	1.70	0.80	16.50	0.40	0.40	0.20	0.40

SPECIFICATIONS

- X50CrSiMnVN16-1
- UNS: S42716
- AMS: 5926



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COMPARISON OF DIFFERENT STEELS

A&D GRADES	Designations	Melting route	C	Cr	Ni	Mo	V	N	Si	Mn
XDBD	X105CrMo17 1.3544 / 440C	Air or Remelt	1.00	17.0	--	0.50	--	--	--	--
RA50YW	80MoCrV42-16 1.3551 / M50 AMS: 6491	VIM + VAR	0.83	4.15	--	4.25	1.00	--	--	--
CX13VD	X12CrNiMoV12-3 1.4933 AMS: 5719	Air or Remelt	0.12	12.0	2.50	1.60	0.30	--	--	--
XD15NW	X40CrMoVN16-2 1.4123 AMS: 5925	ESR	0.42	16.0	--	1.80	0.35	0.20	--	--
SOS3	X45CrSi9-3 1.4718	Air	0.45	9.00	< 0.50	--	--	--	3.00	< 0.60
APZ9	X85CrMoV18-2 1.4748	Air	0.85	17.5	--	2.20	0.45	--	< 1.00	< 1.50
XD16N	X50CrSiMnVN16-1 AMS: 5926	Air	0.50	16.0	--	0.30	0.30	0.10	2.00	1.00
AMS 5749 14.5Cr - 4.0Mo - 1.2V - (1.10 - 1.20C)		VIM + VAR	1.15	14.5	--	4.00	1.20	--	0.30	0.50
AMS 5898 15.2Cr - 1.0Mo - 0.40N - (0.28 - 0.34C)		PESR	0.30	15.0	--	1.00	--	0.40	--	1.00

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COMPARISON OF THE CORE CHARACTERISTICS

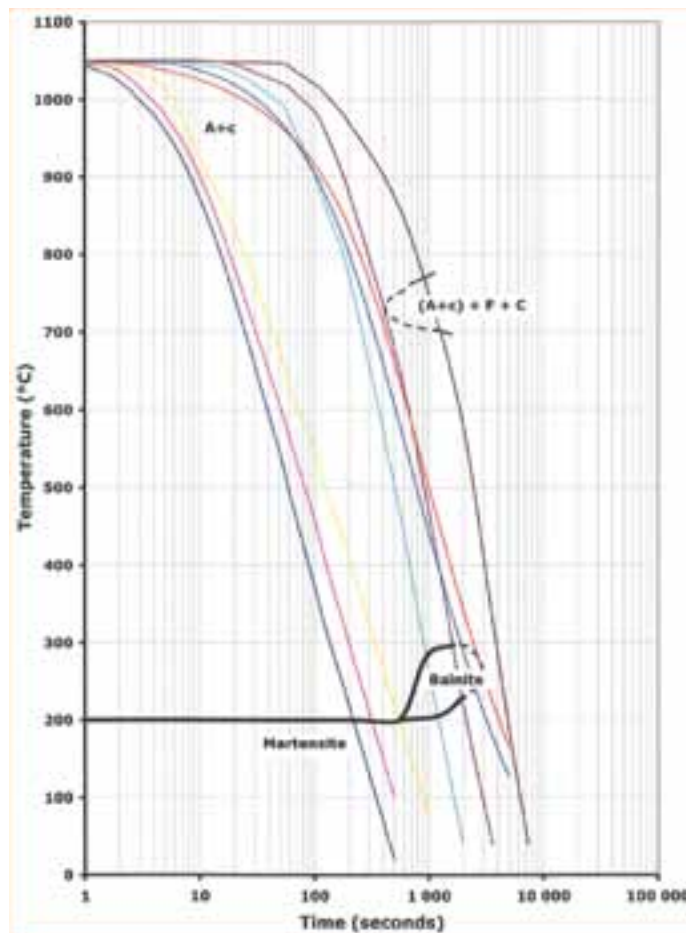
A&D GRADES	Designations	Heat Treatment	UTS (MPa)	0.2% YS (MPa)	KV (J)	K1c (MPa √m)	HRC Surface
XDBD	X105CrMo17 1.3544 / 440C	1040 °C / Oil -75 °C + 140 °C	2500	--	--	--	59
		1040 °C / Oil -75 °C + 450 °C	2350	--	--	--	56
RA50YW	80MoCrV42-16 1.3551 / M50 AMS: 6491	1100 °C / Gas -75 °C + 3x550 °C	2650	--	--	--	62
CX13VD	X12CrNiMoV12-3 1.4933 AMS: 5719	(*) 1050 °C / Oil -75 °C + 250 °C	1350	1000	130	130	--
XD15NW	X40CrMoVN16-2 1.4123 AMS: 5925	1050 °C / Oil -75 °C + 180 °C	2500	--	10	14	59
		1075 °C / Oil -75 °C + 2x500 °C	2500	--	5.5	16	59.5
		1050 °C / Oil 2x650 °C	1200	900	10	66	36
SOS3	X45CrSi9-3 1.4718	1050 °C / Oil 700 °C	1000	750	--	--	--
APZ9	X85CrMoV18-2 1.4748	1080 °C / Oil 730 °C	1000	760	--	--	--
XD16N	X50CrSiMnVN16-1 AMS: 5926	1070 °C / Oil -75 °C + 180 °C	2140	1970	5	--	58
		1075 °C / Oil -75 °C + 2x500 °C	1910	1430	4	--	58
		1050 °C / Oil 2x650 °C	1240	1025	7	--	38
AMS 5749 14.5Cr - 4.0Mo - 1.2V - (1.10 - 1.20C)		1120 °C / Oil -75 °C + 2x525 °C	2600	--	--	--	60
AMS 5898 15.2Cr - 1.0Mo - 0.40N - (0.28 - 0.34C)		1030 °C / Oil -75 °C + 2x200 °C	2480	--	--	17.5	58
		1030 °C / Oil -75 °C + 2x475 °C	2350	--	--	16.7	60
		1000 °C / Oil 2x600 °C	1150	--	--	116	33

(*) After carburizing + annealing

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CCT DIAGRAM



TRANSFORMATION POINTS

γ	1070 °C / 1958 °F
Ac1	875 °C / 1607 °F
Ac3	1000 °C / 1832 °F
Ms	217 °C / 423 °F

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CLEANLINESS

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

A		B		C		D	
Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
≤ 1.0	≤ 0.5	≤ 2.5	≤ 2.0	≤ 1.0	≤ 0.5	≤ 2.0	≤ 1.5

Typical values according to ASTM E 45



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MICROGRAPHIC CHARACTERIZATION

Annealed Condition

The observation of the annealed structure shows a good coalescence of the carbides.



x 100



x 500

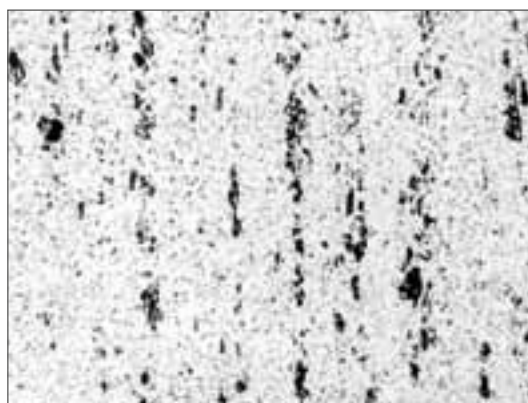
Heat Treated Condition

Compared to X105CrMo17 (440C) the carbides are fine ($10\ \mu\text{m}$) and well distributed within the matrix. The coarse carbides are roughly 20 to $30\ \mu\text{m}$.

Typical aspect of the carbides



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x 200

X105CrMo17

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MECHANICAL CHARACTERISTICS

Annealed condition

Annealing cycle:

850 °C / 1560 °F - 8 hrs slow cooling to 550 °C / 1020 °F - Air

In the annealed condition the hardness is approximately 249 HB. Typical tensile test results on a 20 mm / 0.78 inches diameter bar are as follows:

UTS (MPa / Ksi)	0.2% YS (MPa / Ksi)	EI (%)	RA (%)
860 / 125	620 / 90	19	40

Heat Treated Condition

The heat treatment conditions are optimized in order to jointly obtain the following features:

- Hardness $\geq$ 58 HRC
- Residual Austenite $\leq$ 10 %

For low tempering temperatures (180 °C / 356 °F), the residual austenite content increases with the austenitizing temperature ($\gamma_{res} = 25\%$ at 1100 °C / 2012 °F) and the hardness decreases accordingly.

For tempering at 500 °C / 932 °F, hardening is ensured through the formation of secondary carbides.

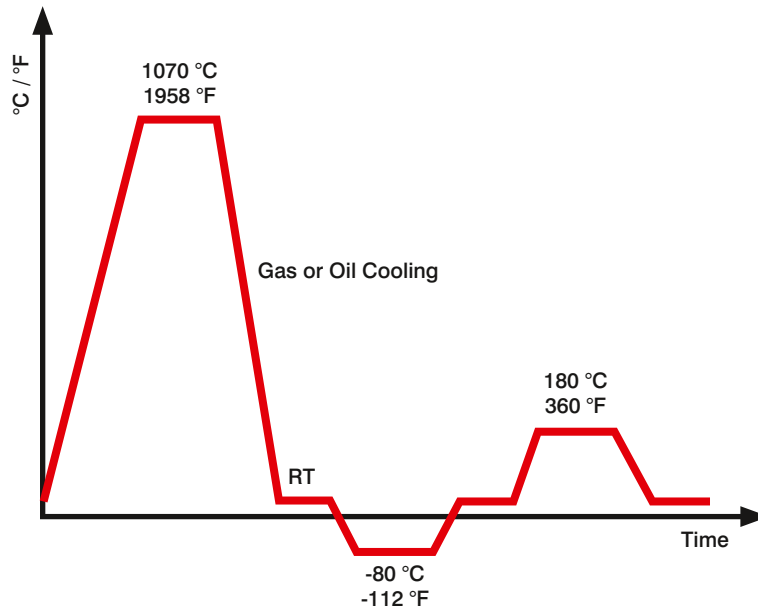
For high tempering temperatures (525 °C / 977 °F):

- A progressive increase of the residual austenite content with the austenitizing temperature.
- A major influence of the double tempering on the residual austenite content.
- An increase of the hardness with the austenitizing temperature up to a certain limit, followed by a drop due to a high residual austenite content.

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Heat treatment for optimized hardness and corrosion resistance

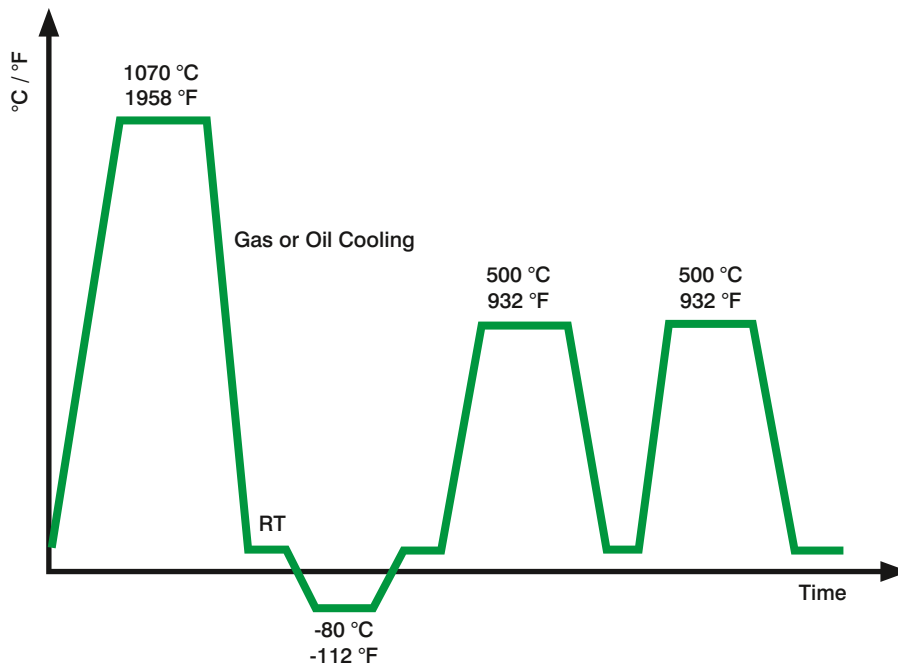


HRC	58
HV	670
UTS	2140 MPa - 310 Ksi
0.2% YS	1970 MPa - 286 Ksi
EI	0.3%
RA	1 %
Charpy V	5 J - 3.6 ft.lb

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Heat treatment cycle optimized for high operating temperatures, high hardness and moderate corrosion resistance



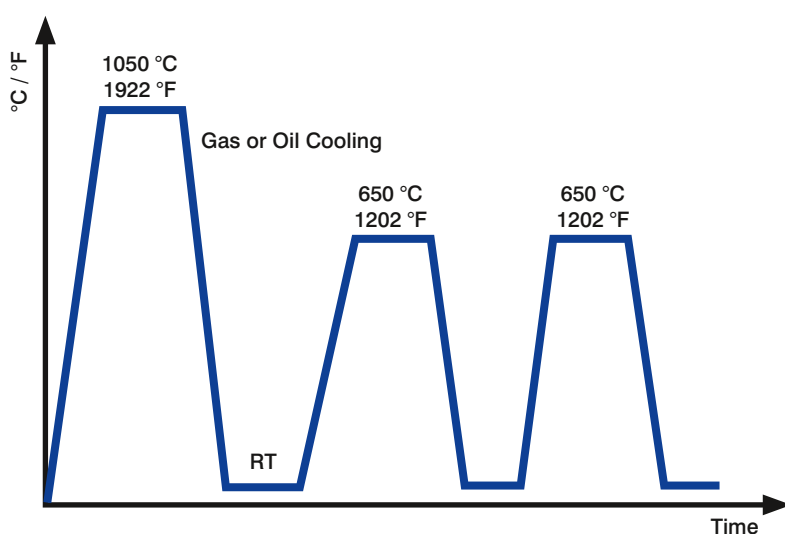
HRC	58
HV	663
UTS	1910 MPa - 277 Ksi
0.2% YS	1430 MPa - 207 Ksi
EI	0.5%
RA	2%
Charpy V	4 J - 3 ft.lb



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Recommended heat treatment cycle for subsequent surface induction hardening. The tempering temperature can be adapted to the required core hardness



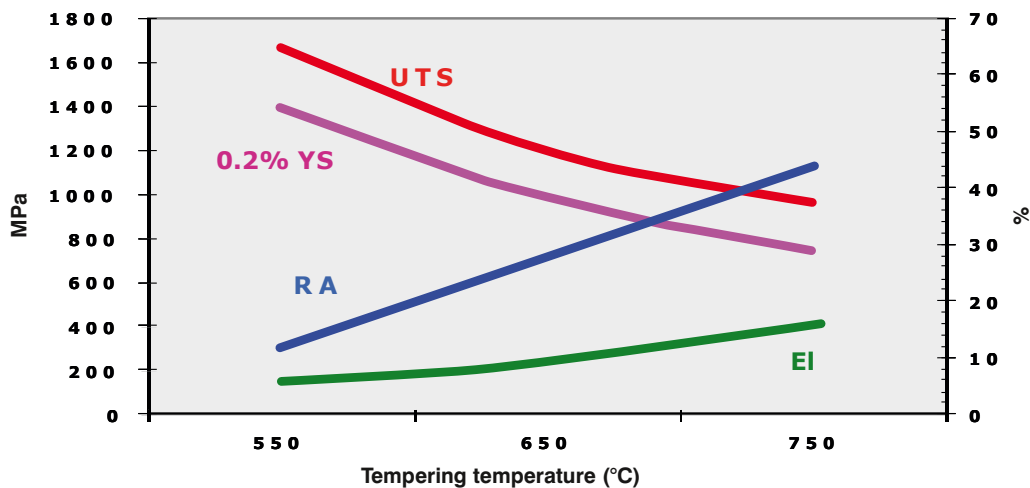
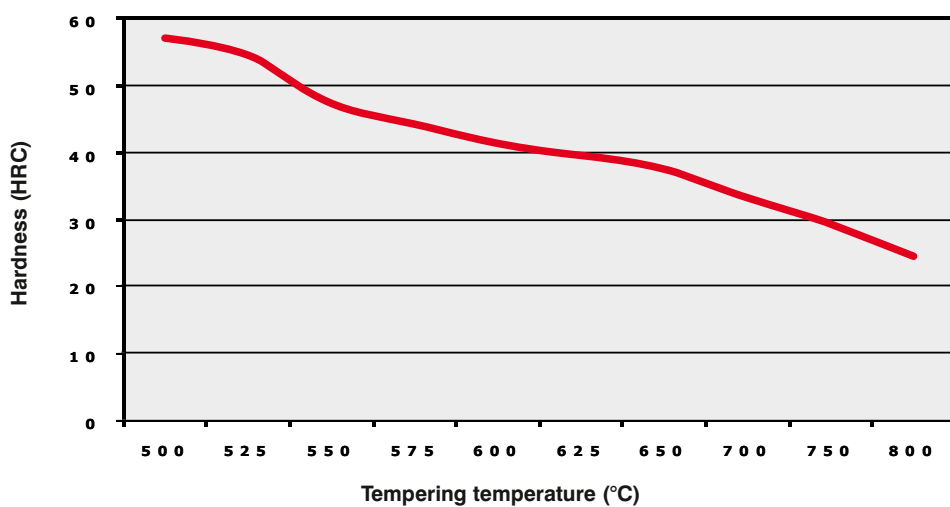
HRC	38
HV	380
UTS	1240 MPa - 180 Ksi
0.2% YS	1025 MPa - 149 Ksi
EI	7 %
RA	21 %
Charpy V	7 J - 5 ft.lb

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Tensile properties as result of the tempering temperature

- Quenched from 1050 °C / 1920 °F – 30 mn – Air
- Tempered 2 hrs at temperature (550 – 750 °C / 1020 – 1380 °F)



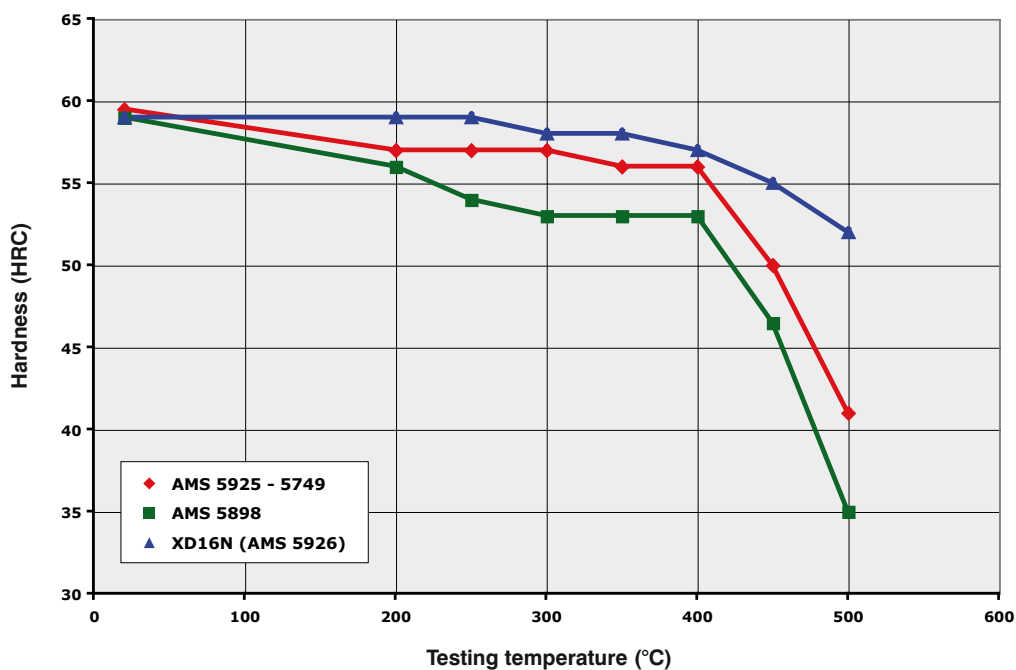
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Properties at temperature

Hardness at temperature

- Quenched from 1050 °C / 1920 °F – 30 mn – Air
- Tempered 2 hrs at temperature (550 – 750 °C / 1020 – 1380 °F)



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Tensile test at elevated temperature

Air quench from 1050 °C / 1920 °F – Temper at **650 °C / 1200 °F** – 2 hrs

Temperature (°C / °F)	UTS (MPa / Ksi)	0.2% YS (MPa / Ksi)	EI (%)	RA (%)
20 / 68	1240 / 180	1025 / 149	9	28
500 / 930	740 / 107	590 / 86	16	53
600 / 1110	420 / 61	300 / 44	42	88
650 / 1200	310 / 45	115 / 17	44	93

Air quench from 1050 °C / 1920 °F – Temper at **750 °C / 1380 °F** – 2 hrs

Temperature (°C / °F)	UTS (MPa / Ksi)	0.2% YS (MPa / Ksi)	EI (%)	RA (%)
20 / 68	955 / 138	760 / 110	16	44
500 / 930	590 / 86	500 / 73	20	59
600 / 1110	360 / 52	260 / 38	33	87
700 / 1290	175 / 25	115 / 17	42	96



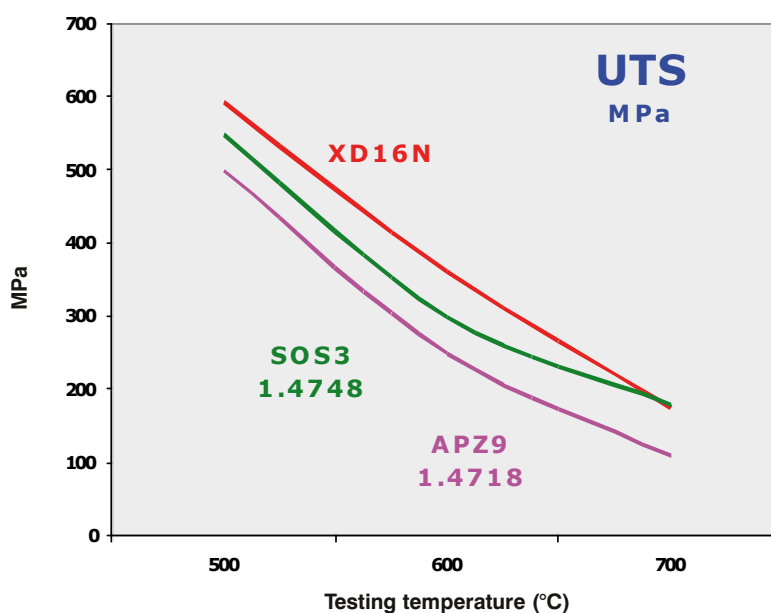
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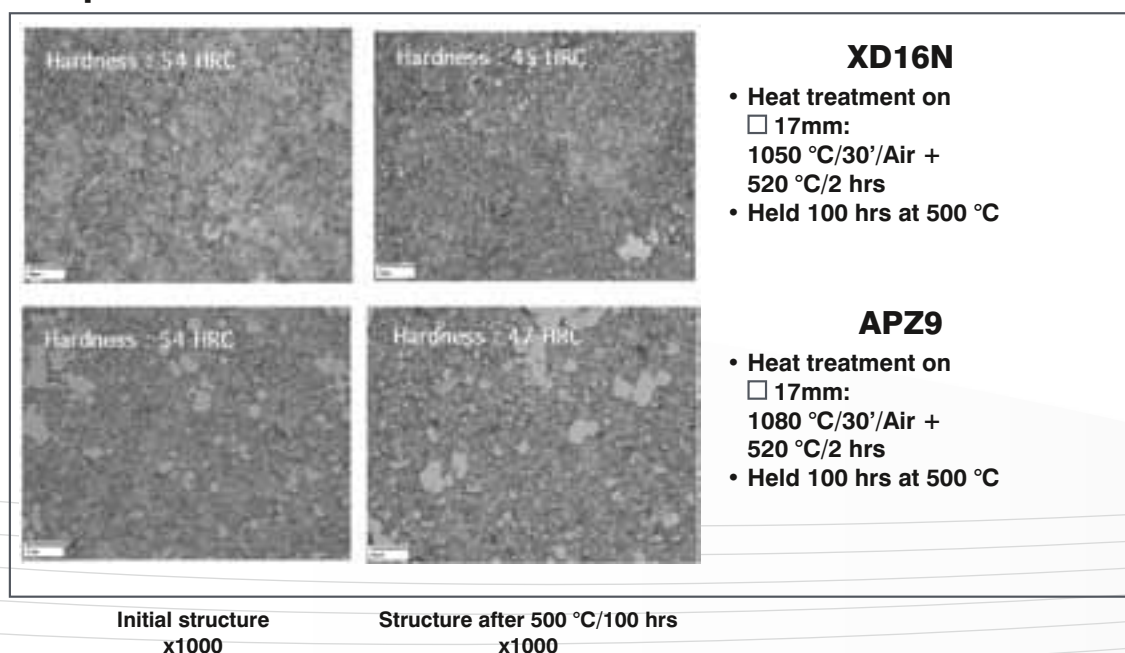
Tensile test at elevated temperature

XD16N: 1050 °C / 1920 °F – 30 min – Air + 750 °C / 1200 °F – 2 hrs

SOS3 (1.4748) – **APZ9** (1.4718): heat treated and typical values according to EN10090



Evolution of the structure at temperature Comparison with APZ9



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CORROSION RESISTANCE

The corrosion resistance is characterized with the following test:

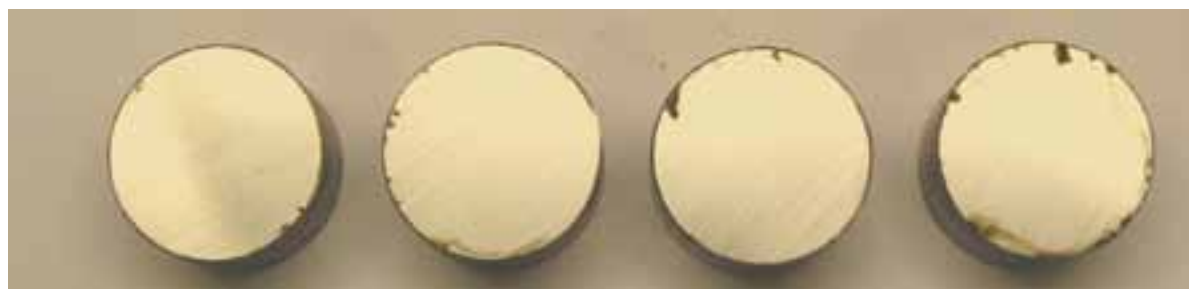
- Salt spray test according to NF X 41-002

As shown in the pictures below, the corrosion resistance is significantly better when compared to the standard solution X105CrMo17 (440C).

Surface aspect after different salt spray (NaCl) exposure times.

XD16N - heat treatment cycle:

1070 °C / 1958 °F Oil – (-75 °C / -103 °F) - 180 °C / 356 °F



t: 2 hrs

t: 8 hrs

t: 48 hrs

t: 100 hrs

X105CrMo17 - heat treatment cycle:

1050 °C / 1922 °F Oil – (-75 °C / -103 °F) – 140 °C / 284 °F



t: 2 hrs

t: 8 hrs

t: 48 hrs

t: 100 hrs

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MACHINING

The parameters presented below are indicative only. These parameters have to be optimized based on the type of machining, machines, tools, know-how...

ANNEALED CONDITION

Turning (insert)

Roughing

- Speed: 65 m/min
- Feed: 0.50 mm/rev
- Depth: 2 to 5 mm
- Intensive lubrication

Finishing

- Speed: 70 m/min
- Feed: 0.10 to 0.30 mm/rev
- Depth: 0.3 to 0.5 mm
- Intensive lubrication

Milling (insert)

Roughing

- Speed: 65 m/min
- Feed: 0.15 mm/tooth
- Depth: 2 to 5 mm
- Intensive lubrication

Finishing

- Speed: 70 m/min
- Feed: 0.12 mm/tooth
- Depth: 0.3 to 1.5 mm
- Intensive lubrication

Drilling (carbide tool)

- Drill diameter: 3 to 30 mm
- Cutting speed: 60 m/min
- Feed: 0.07 to 12 mm/rev

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