AUBERT&DUVAL

# XD16N™

## X50CrSiMnVN16-1

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

CONTINUOUS
METALLURGICAL
INNOVATION

SPECIAL STEELS

DEVELOPMENT

RESEARCH

SERVICE

Enhancing your performance

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# XD16N

**X50CrSiMnVN16-1**

## 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

UNS: S42716
AMS 5926

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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

# XD16N

**X50CrSiMnVN16-1**

## COMPARISON OF DIFFERENT STEELS

| A&D GRADES | Designations | Melting route | C | Cr | Ni | Mo | V | N | Si | Mn |
|---|---|---|---|---|---|---|---|---|---|---|
| **XDBD** | X105CrMo17<br>1.3544 / 440C | Air<br>or Remelt | 1.00 | 17.0 | -- | 0.50 | -- | -- | -- | -- |
| **RA50YW** | 80MoCrV42-16<br>1.3551 / M50<br>AMS: 6491 | VIM + VAR | 0.83 | 4.15 | -- | 4.25 | 1.00 | -- | -- | -- |
| **CX13VD** | X12CrNiMoV12-3<br>1.4933<br>AMS: 5719 | Air<br>or Remelt | 0.12 | 12.0 | 2.50 | 1.60 | 0.30 | -- | -- | -- |
| **XD15NW** | X40CrMoVN16-2<br>1.4123<br>AMS: 5925 | ESR | 0.42 | 16.0 | -- | 1.80 | 0.35 | 0.20 | -- | -- |
| **SOS3** | X45CrSi9-3<br>1.4718 | Air | 0.45 | 9.00 | < 0.50 | -- | -- | -- | 3.00 | < 0.60 |
| **APZ9** | X85CrMoV18-2<br>1.4748 | Air | 0.85 | 17.5 | -- | 2.20 | 0.45 | -- | < 1.00 | < 1.50 |
| **XD16N** | X50CrSiMnVN16-1<br>AMS: 5926 | Air | 0.50 | 16.0 | -- | 0.30 | 0.30 | 0.10 | 2.00 | 1.00 |
| | | | | | | | | | | |
| **AMS 5749**<br>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**<br>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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# XD16N

**X50CrSiMnVN16-1**

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

(*) After carburizing + annealing

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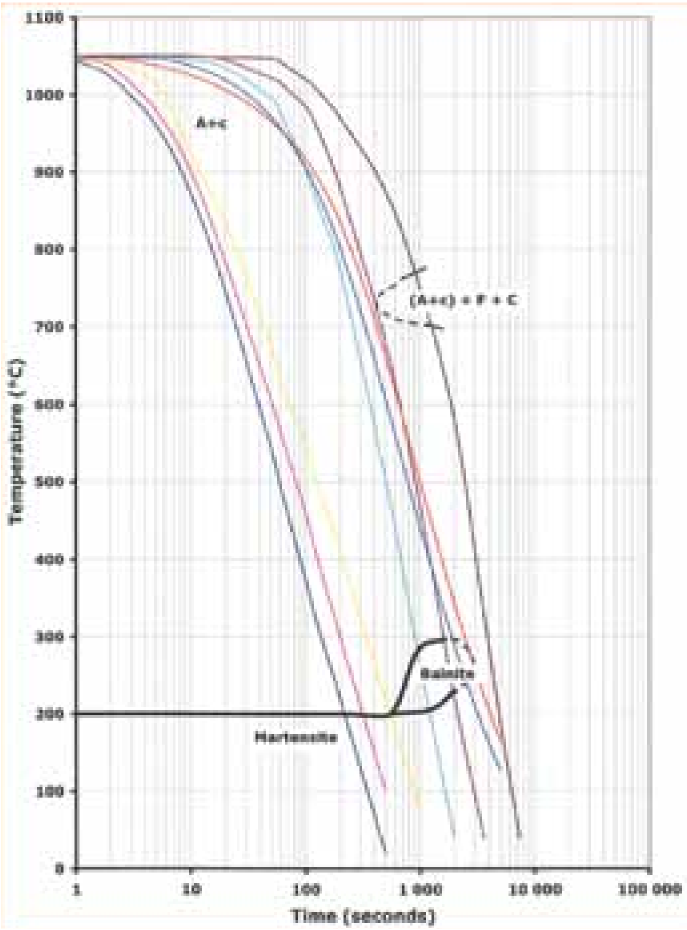
**X50CrSiMnVN16-1**

## 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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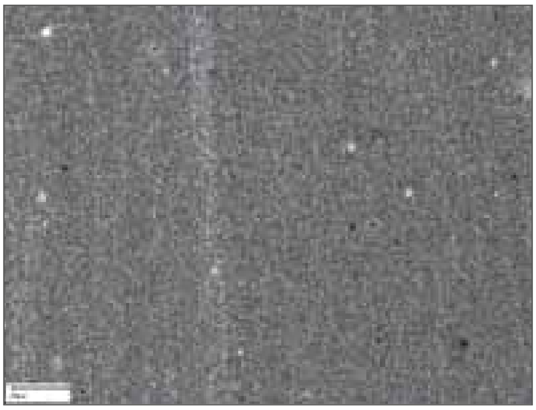
**X50CrSiMnVN16-1**

## MICROGRAPHIC CHARACTERIZATION

### Annealed Condition

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



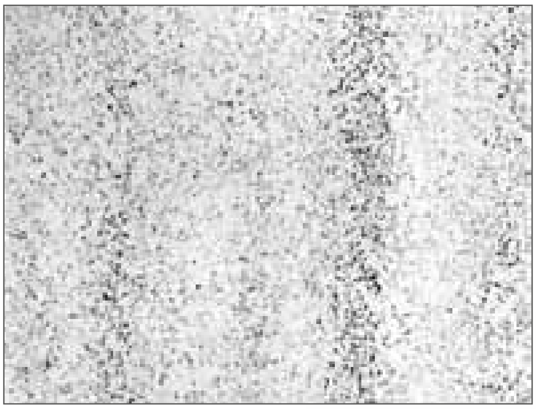
x 100

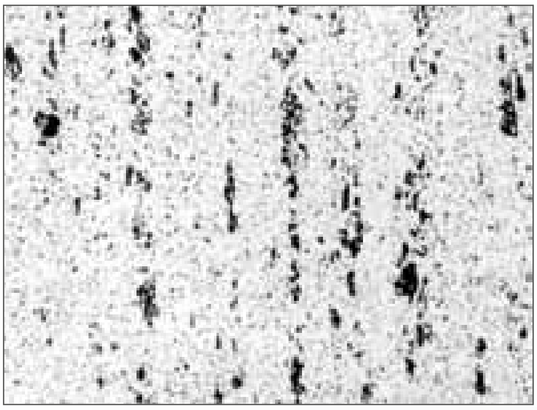
x 500

### Heat Treated Condition

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

Typical aspect of the carbides





XD16N x 200 X105CrMo17

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# XD16N

**X50CrSiMnVN16-1**

## 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) | **El** (%) | **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 ≥ 58 HRC
- Residual Austenite ≤ 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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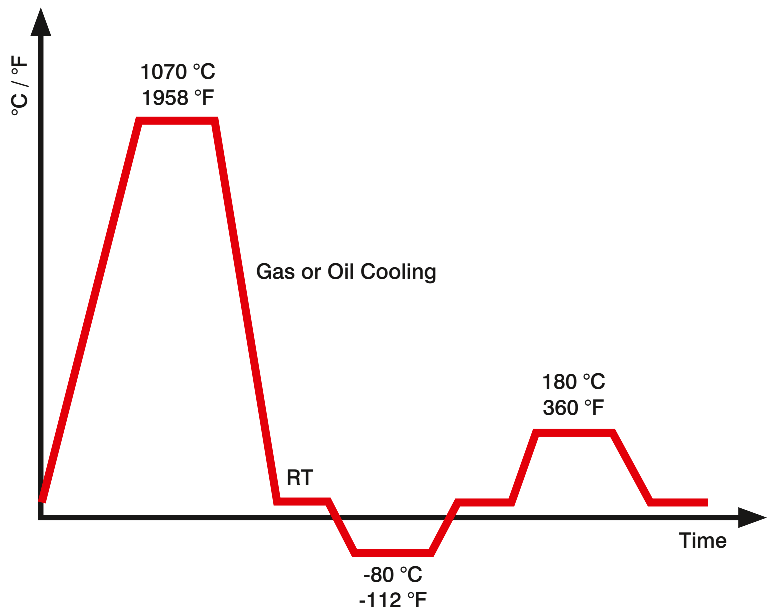
X50CrSiMnVN16-1

## Heat treatment for optimized hardness and corrosion resistance




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

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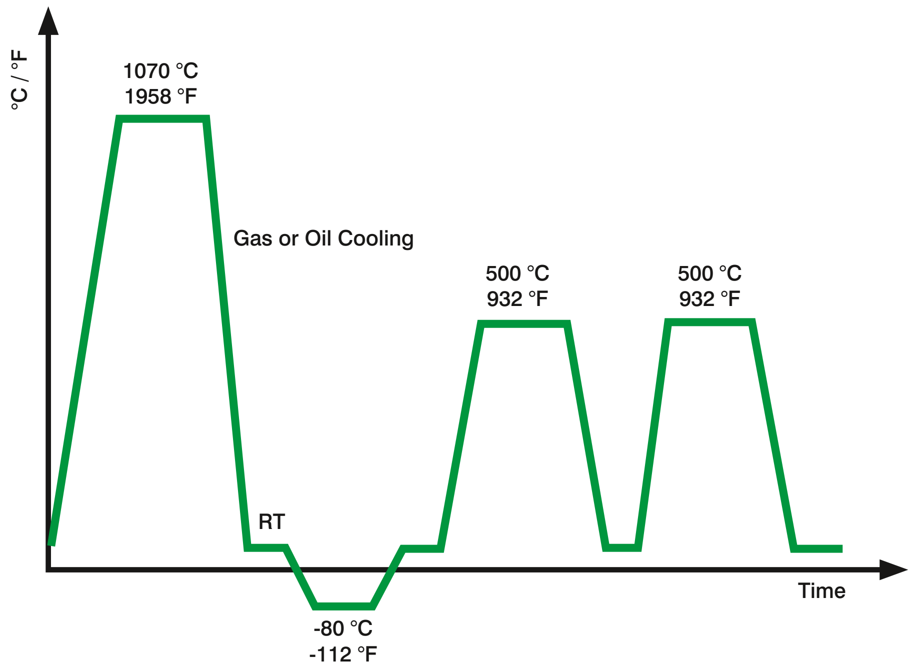
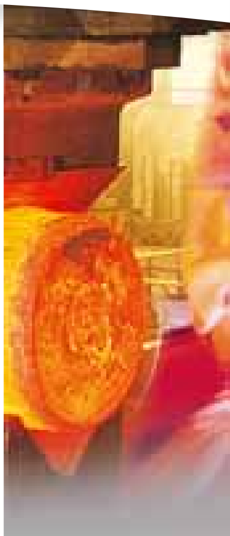
# XD16N

**X50CrSiMnVN16-1**

**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** |
| **El** | **0.5%** |
| **RA** | **2%** |
| **Charpy V** | **4 J - 3 ft.lb** |



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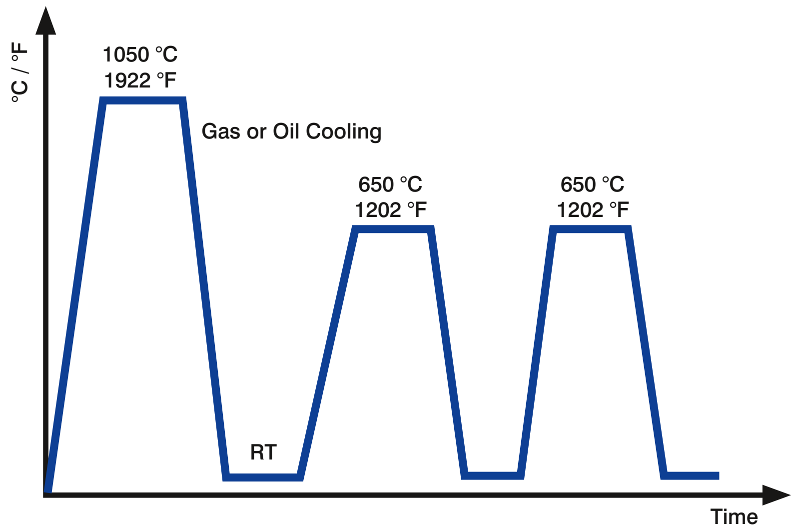
**Recommended heat treatment cycle for subsequent surface induction hardening. The tempering temperature can be adapted to the required core hardness**




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

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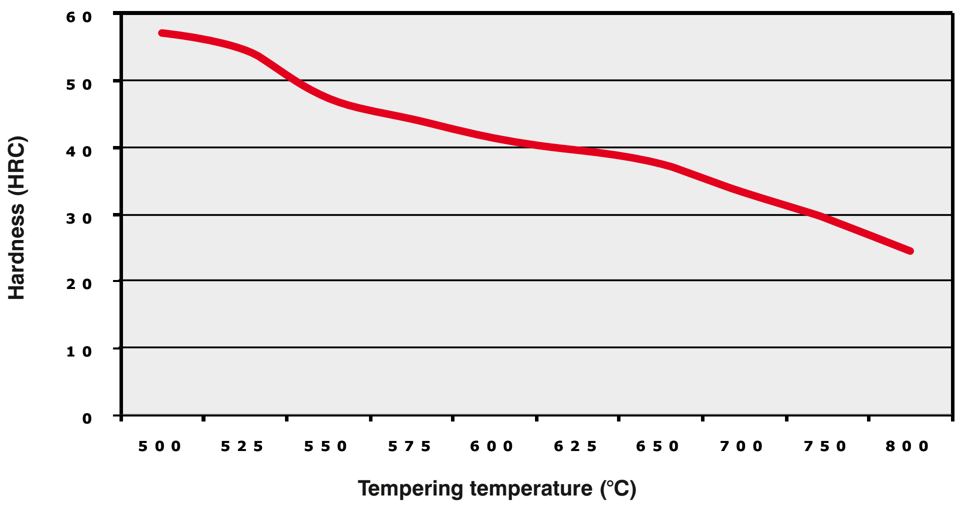
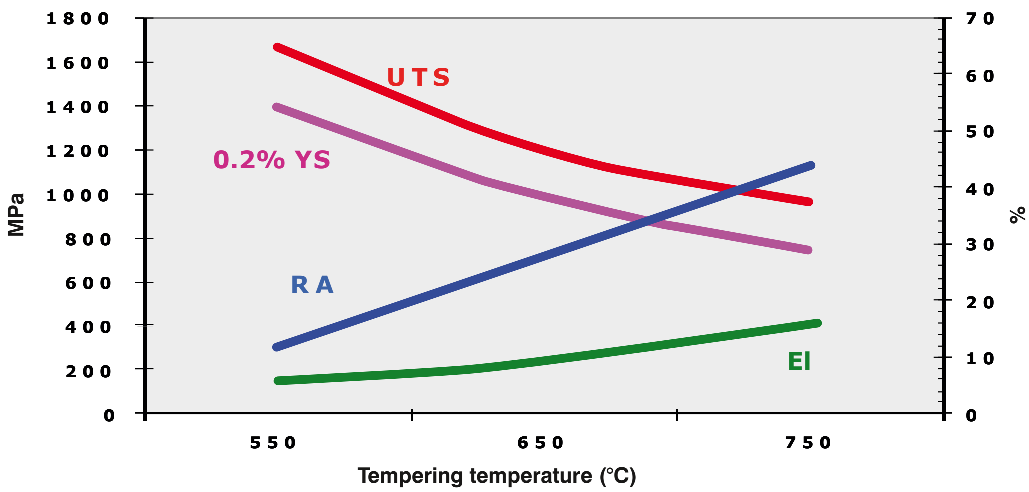
## Tensile properties as result of the tempering temperature

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

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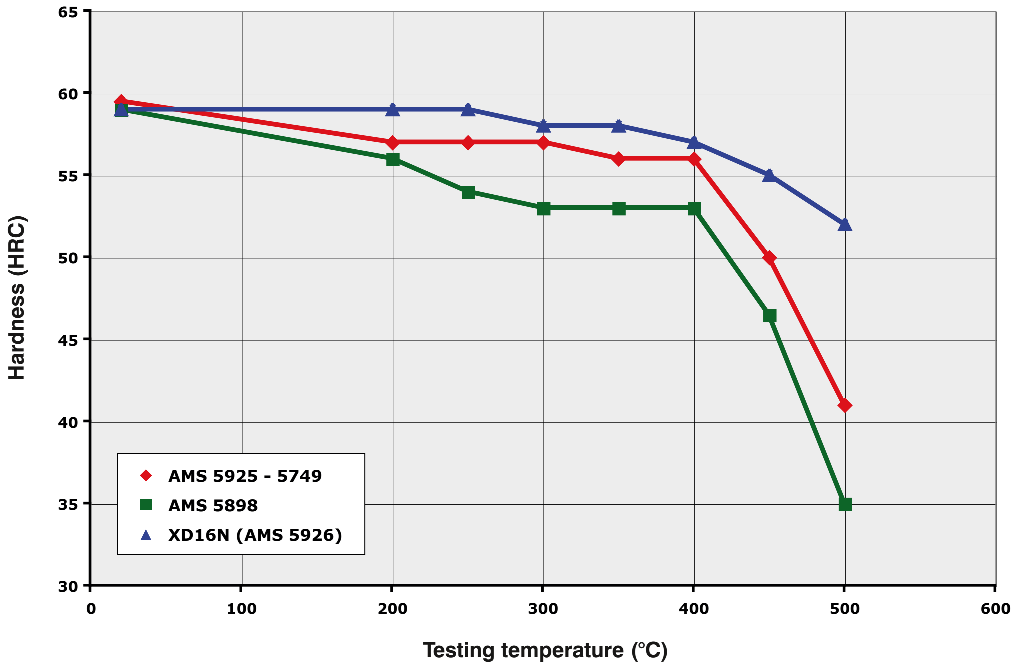
## Properties at temperature

### 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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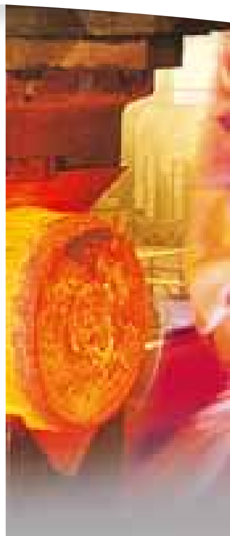

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## Tensile test at elevated temperature

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) | **El** (%) | **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) | **El** (%) | **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 |

# XD16N

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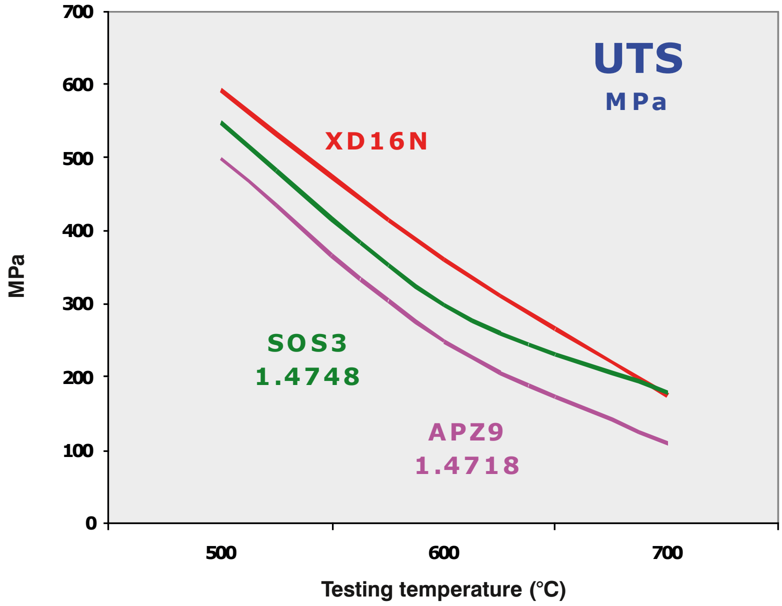
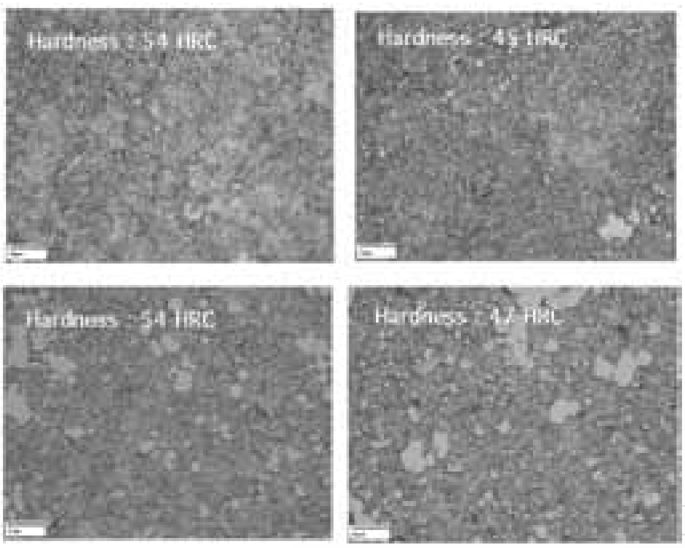
## Tensile test at elevated temperature

**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




**XD16N**

- **Heat treatment on □ 17mm: 1050 °C/30'/Air + 520 °C/2 hrs**
- **Held 100 hrs at 500 °C**

**APZ9**

- **Heat treatment on □ 17mm: 1080 °C/30'/Air + 520 °C/2 hrs**
- **Held 100 hrs at 500 °C**

**Initial structure x1000** — **Structure after 500 °C/100 hrs x1000**

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# XD16N

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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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**NOTES:**

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**Design:** affinity makheia group

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