AUBERT&DUVAL

X15TN™

X40CrMoVN16-2

A high hardness, corrosion and fatigue resistance martensitic grade

CONTINUOUS
METALLURGICAL
INNOVATION

SPECIAL STEELS

DEVELOPMENT

RESEARCH

SERVICE

Enhancing your performance

X15TN

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THE INDUSTRIAL ENVIRONMENT

Numerous applications require the use of stainless steel resisting high mechanical stresses and abrasive or corrosive environments.

For fuel injection systems, pollution control devices, tools used for medical applications or knives, the required hardness often exceeds 55 or even 58 HRC. The choice of stainless grades then becomes quite limited. Starting from the high alloyed martensitic steels down to precipitation hardening stainless steels, hardness and abrasion resistance decrease while corrosion resistance increases.
A very common grade used is AISI 440C / X105CrMo17, and the associated compositions with slight variations of carbon, chromium or molybdenum. Addition of other elements like tungsten, vanadium and niobium can be made in order 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.

Such high carbon content has the following consequences:

- Coarse carbide structures
- Localized Cr depletion around large carbides
- High sensitivity to tempering temperature 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 X15TN

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

- High fracture toughness combined with high hardness, typically 58 HRC.
- 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. For steels containing 13-17 % of Cr, the addition of nitrogen through a conventional melting method allows a saturation content of ca 0.20 %. In combination with 0.4% to 0.5% carbon:
  - > A minimum hardness of 55 or 58 HRC can be ensured,
  - > A microstructure of fine eutectic carbides is obtained.
- Nitrogen combined with chromium and molybdenum plays a favorable role in pitting corrosion resistance.
- Molybdenum and vanadium ensure a secondary hardening. These elements replace chromium in the precipitates. The chromium content in the matrix is kept at a high level, therefore contributing to an improved corrosion resistance, even when tempering at high temperature.

APPLICATIONS

- Fuel injection, pollution control systems in abrasive / corrosive environments (biofuels, combustion gases)
- Cutting blades with high requirements on corrosion resistance
- Surgical instruments
- Mold components for synthetic material processing
- Glassware molds

CHEMICAL COMPOSITION

	C	Si	Mn	Cr	Mo	V	N	Ni
min.	0.37	-	-	15.00	1.50	0.20	0.16	-
max.	0.45	0.60	0.60	16.50	1.90	0.40	0.25	0.30

SPECIFICATIONS

- X40CrMoVN16-2
- UNS: S42025
- Euro Number: 1.4123

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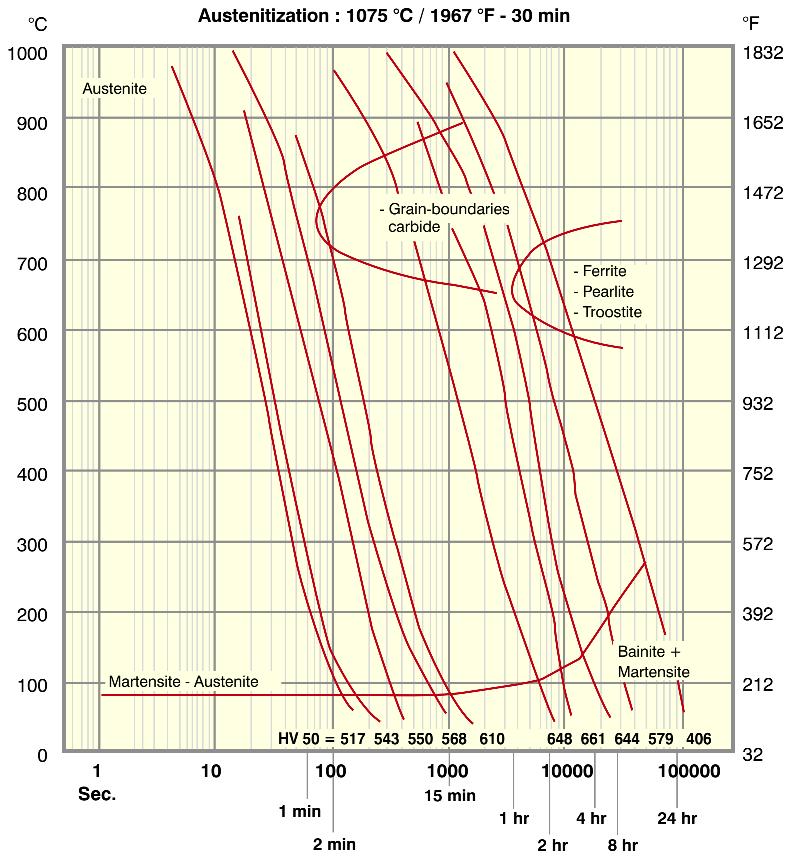
CCT DIAGRAM



Transformation Points

γ	1050 °C	1075 °C
Ac1	850 / 870 °C	
Ac3	890 / 900 °C	
Ms	120 / 130 °C	80 / 100 °C
Mf	- 50 / - 60 °C	- 80 / - 100 °C

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MACROSTRUCTURE

The segregation observed in the ingots is well within the limits of the aerospace industry requirements:

Class	Type	Severity
1	Freckles	A
2	White spots	A
3	Radial segregation	B
4	Ring pattern	B

Macrostructure according to ASTM A 604

CLEANLINESS

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

Typical values according to ASTM E45

A		B		C		D	
Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
0	0	≤ 1	0	0	0	1	0.5

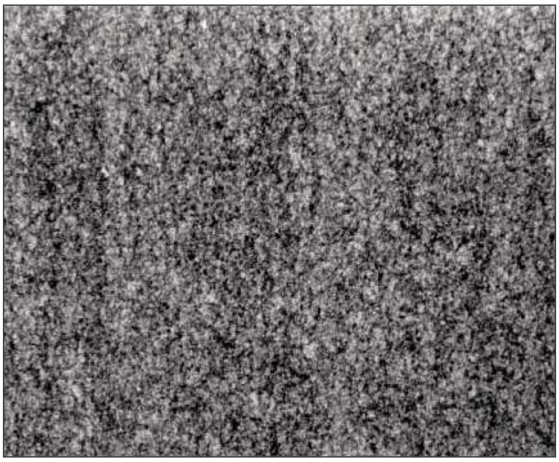
Typical Values according to DIN 50602

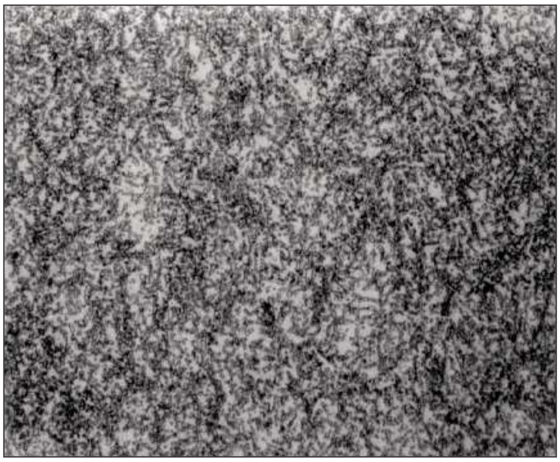
K1 ≤ 3

MICROGRAPHIC CHARACTERIZATION

Annealed Condition

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



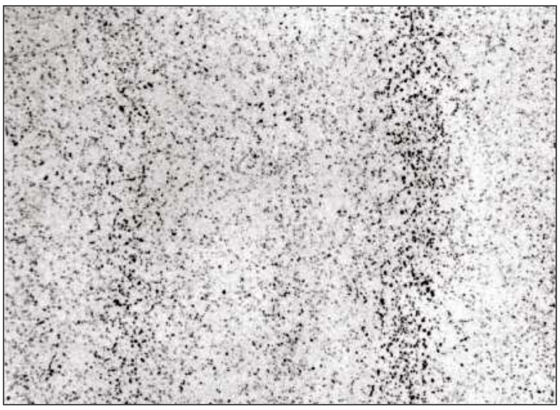


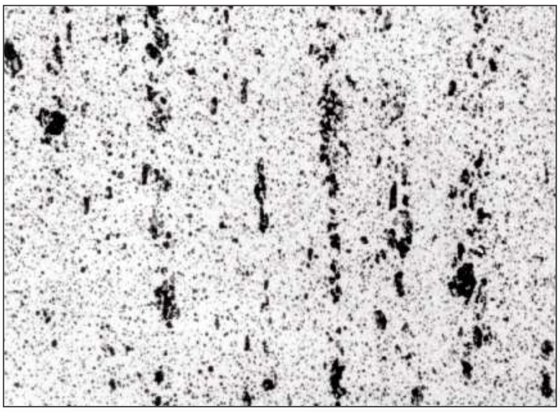
x 100 **X15TN** **x 500**

Heat Treated Condition

Compared to X105CrMo17 (AISI 440C) the carbides are small (3 - 4 μm to 10 μm depending on the section) and well distributed within the matrix. The coarsest carbides are roughly 20 to 30 μm.

Typical Aspect of the carbides





X15TN **x 200** **X105CrMo17**

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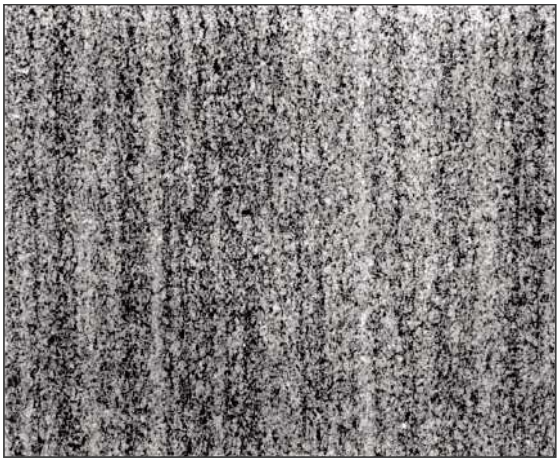
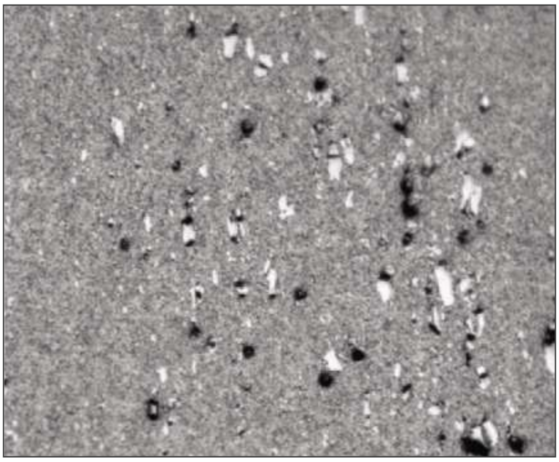
Typical Structure of grades X15TN
and X105CrMo17 in the used condition





X15TN **x 100** **X105CrMo17**

MECHANICAL CHARACTERISTICS

Annealed Condition

Annealing cycle:

860 °C / 8 h slow cooling to 550 °C / Air

In the annealed condition the hardness is approximately 250 HB. Typical tensile test results on a 22 mm diameter bar are as follows:

UTS (MPa)	0.2% YS (MPa)	El (%)	RA (%)
820	550	16	45

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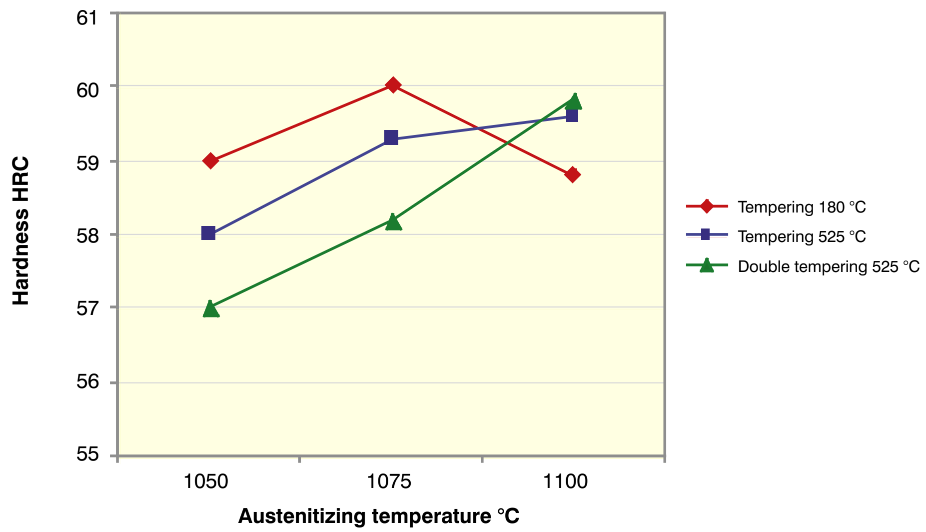
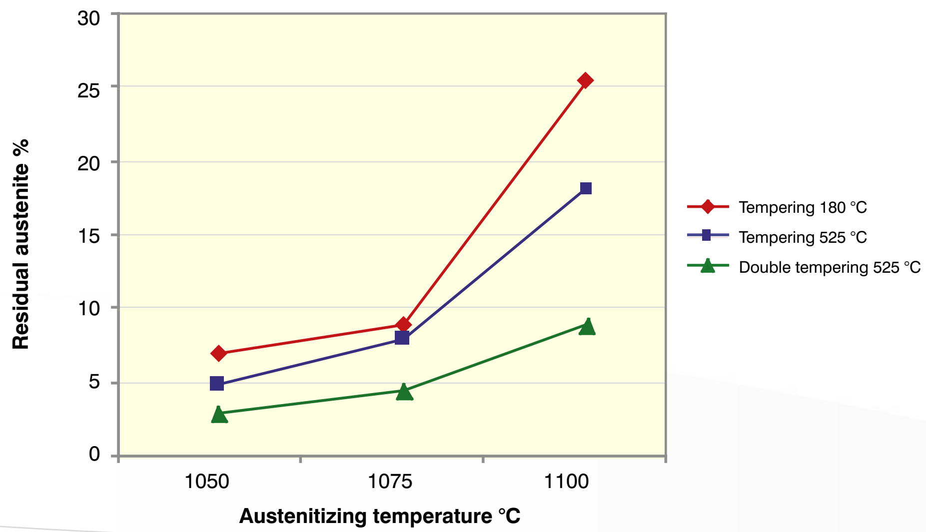
Heat Treated Condition

The heat treatment conditions are optimized in order to obtain simultaneously:

- Hardness ≥ 58 HRC
- Retained Austenite ≤ 10 %

The following graphs show the influence of the heat treatment conditions on hardness and retained austenite content.





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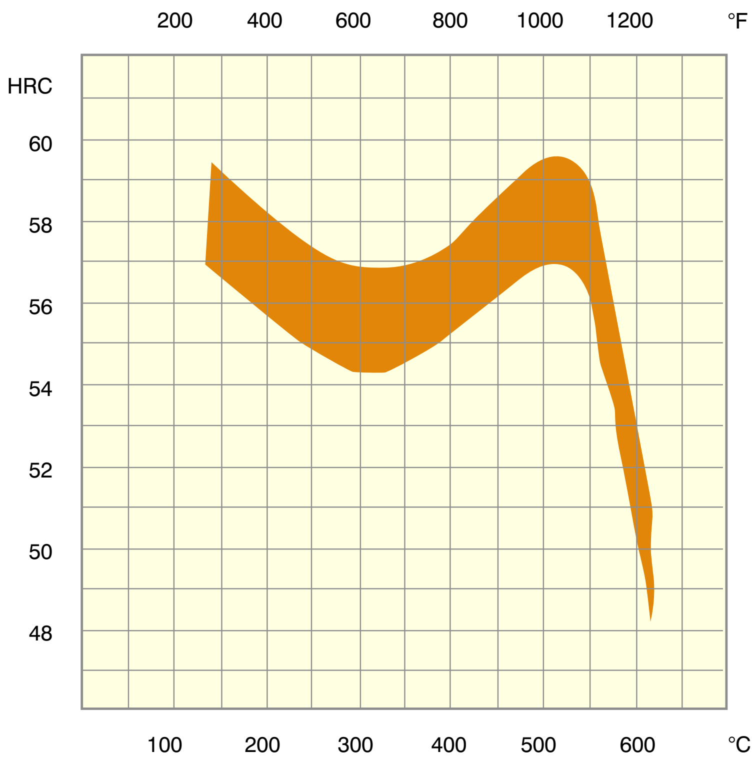
For low tempering temperatures (180°C), the retained austenite content increases with the austenitizing temperature (γret = 25% at 1100°C) and hardness decreases accordingly.

For high tempering temperatures (525 °C):

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

The hardness spread for austenitizing temperatures between 980 °C and 1080 °C is shown below:



Based on these results, optimized heat treatment conditions are presented in the following tables and graphs.

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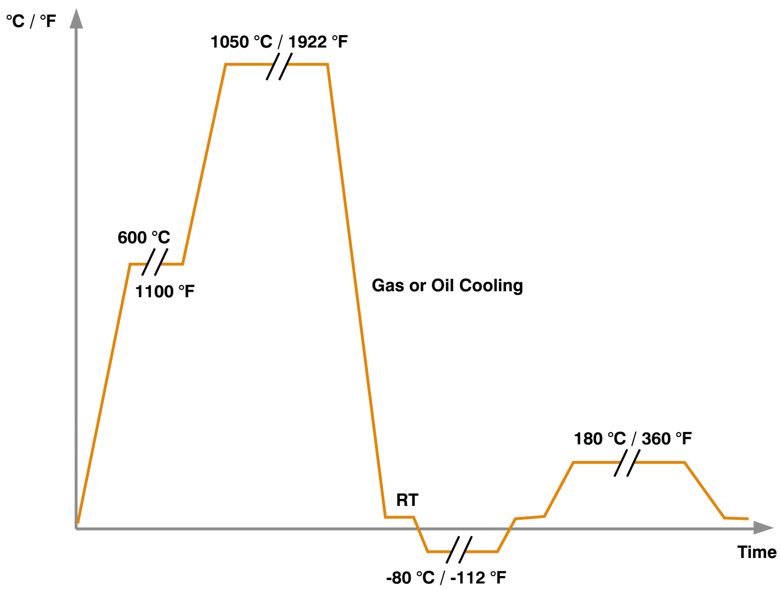
Heat treatment for optimized hardness and corrosion resistance.



HRC	59
HV	685
Austenite	9 %
UTS	2320 MPa - 336 ksi
0.2 % YS	1825 MPa - 265 ksi
E	4 %
RA	10%
Charpy V	10 J - 7.5 ft.lb
K1c	14 MPa√m - 12.7 Ksi√in
Endurance limit 10^7 cycles (Rotative bending)	928 MPa - 135 Ksi

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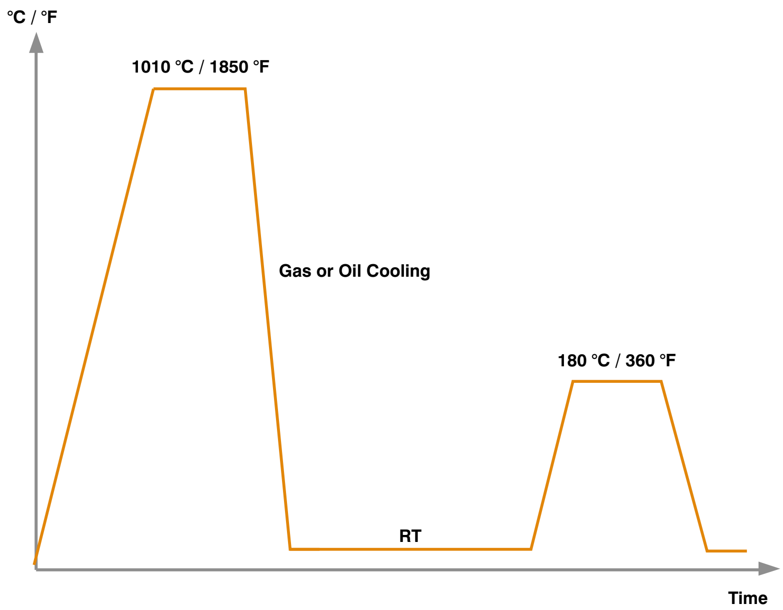
Heat treatment recommended for a good corrosion resistance and increased toughness.



HRC	56.5
HV	630
Austenite	9 %
UTS	2160 MPa - 313 ksi
0.2 % YS	1610 MPa - 233 ksi
E	4 %
RA	12 %
Charpy V	20 J - 7.5 ft.lb
K1c	16.5 MPa√m - 18.2 Ksi√in
Endurance limit 10^7 cycles (Rotative bending)	865 MPa - 125 Ksi

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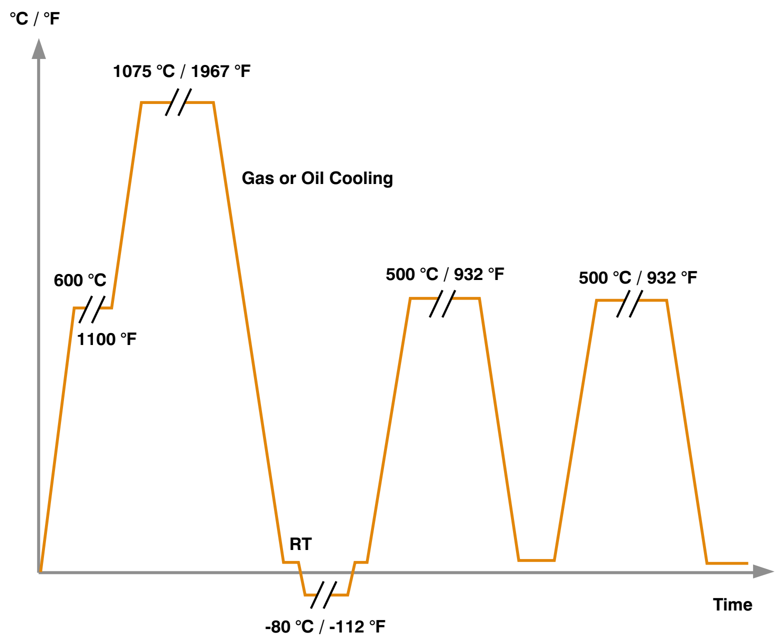
Heat treatment cycle optimized for high working temperatures, high hardness and moderate corrosion resistance.



HRC	59.5
HV	700
Austenite	12 %
UTS	2350 MPa - 340 ksi
0.2 % YS	1580 MPa - 229 ksi
E	4 %
RA	10 %
Charpy V	5.5 J - 4.5 ft.lb
K1c	16 MPa√m - 14.6 Ksi√in
Endurance limit 10^7 cycles (Rotative bending)	954 MPa - 138 Ksi

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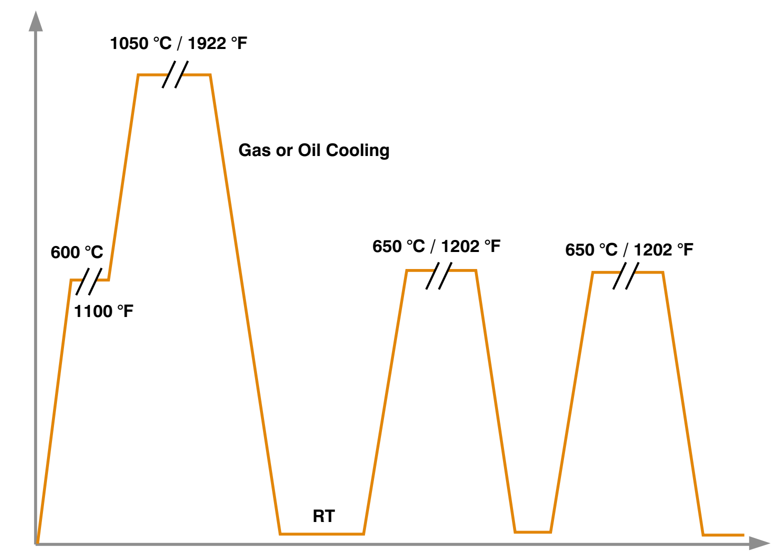
Recommended heat treatment cycle for subsequent surface induction hardening.
The tempering temperature can be adapted to the required core hardness.



HRC	36
Austenite	12 %
UTS	1200 MPa - 174 ksi
0.2 % YS	900 MPa - 131 ksi
E	12 %
RA	40 %
Charpy V	10 J - 7.5 ft.lb
K1c	66 MPa√m - 60 Ksi√in
Endurance limit 10^7 cycles (Rotative bending)	640 MPa - 131 Ksi

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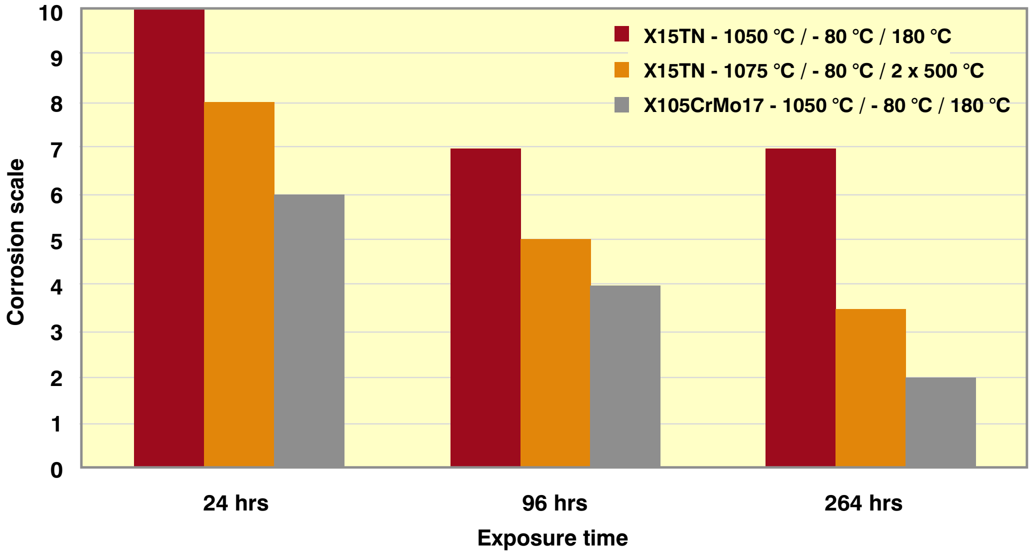
CORROSION RESISTANCE

The corrosion resistance is characterized below with two different tests:

- Salt spray test according to NF X 41-002
- Electrochemical test (potentiocinetic) - H_2SO_4 – 1% - de-aerated solution

Salt spray test

The results are presented with a normalized scale based on how much surface area of the test piece has been oxyded.



These results show the benefit of low temperature tempering in terms of corrosion resistance compared to higher tempering conditions. The decrease in corrosion resistance for the higher tempering temperature is due to the formation of secondary carbides, which consume part of the chromium. The matrix is therefore less rich in chromium and less resistant to corrosion.

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

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X105CrMo17 (440C)

Aspect of the surface after a 96 h salt spray (NaCl) exposure.
For both grades, heat treatment cycle: 1050 °C Oil / -80 °C / 180 °C.

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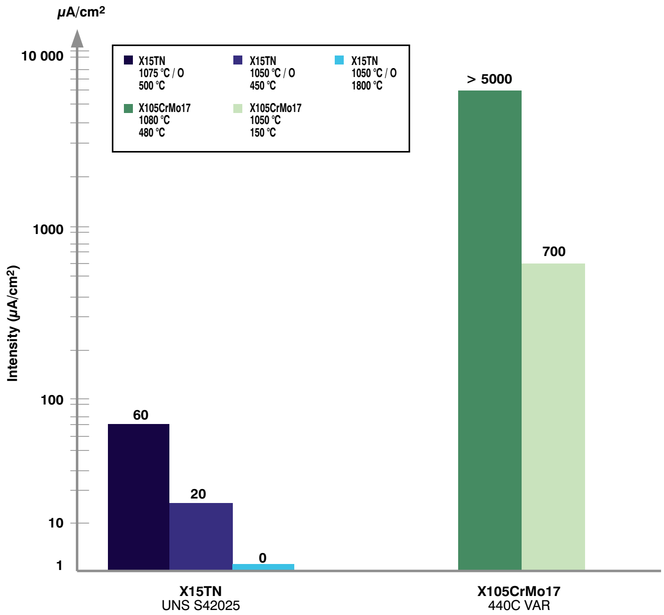
Potentiocinetic corrosion in de-aerated H_2SO_4 - 1 % solution

The following graph shows the response to this test. The superiority of X15TN over 440C (X105CrMo17) is confirmed.



Current density results

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

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

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.

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Design:

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