High Yield Strength Alloys

PHYNOX

PHYNOX (AFNOR designation K13 C20 N16 Fe 15 D07) is an austenitic alloy strengthened by cold work and capable of additional hardening by aging at a moderate temperature (around 500°C).
In the fully hardened condition, its elastic modulus is around 210 000 MPa, with UTS levels up to 2500 MPa on cold rolled strip.

General characteristics

In addition to its very high yield strength, PHYNOX offers a range of physical, chemical and technological properties that make it appropriate for a wide variety of applications.

The most important complementary properties are:

- Exceptional resistance to corrosion, stress corrosion cracking and hydrogen embtittlement.
- Good fatigue strength.
- The absence of aging in service.
- The absence of magnetism.
- Ability to be used over a wide range of temperatures, from liquid helium to about 500°C.
- Perfect passivity in contact with human tissues.
- The possibility of increasing the strength of parts by age hardening after forming, leading to strength levels unattainable with other materials.
- The absence of brittleness at low temperatures (no transition temperature).
- A maximum service temperature about 100°C higher than for stainless steels.
- A corrosion resistance vastly superior to that of molybdenum-containing stainless steels.
- A very high yield strength that combined with a high elastic modulus in both tension and torsion, enables the storage and rapid release of large amounts of elastic energy.

PHYNOX often provides the best solution whenever high mechanical performance is required under severely corrosive service conditions.

PHYNOX finds numerous applications in watch making, surgical implants, metrology, electronics and aeronautical engineering:

- Springs for watch motors.
- Shaped springs (helical, etc...).
- Flexible couplings.
- Electrical and electronic apparatus.
- Equipment for the chemicals and oil & gas industries.
- Aeronautical and aerospace equipment.
- Automotive injection systems.
- Various diaphragms.
- Naval equipment.
- Weaponry.
- Prostheses for osteosynthesis.
- Pacemaker electrodes.
- Special collars for missiles.
- Automotive ABS systems.
- Surgical implants and medical instruments.
- Printer springs.

Chemical composition

Elements (% weight)	Co	Cr	Ni	Mo
Balance Iron	40	20	16	7

Physical properties

Properties	Units	Values
Melting temperature	°C	1450 - 1460
Density	$g.cm^{-3}$	8.3
Electrical resistivity at 20°C	µΩ.cm	95
Specific heat	$J.kg^{-1}.°C^{-1}$	450
Variation of resistivity with temperature between 0 and 300 °C: annealed condition	$µΩ.cm\ °C^{-1}$	4×10^{-4}
Variation of resistivity with temperature between 0 and 300 °C: cold worked condition	$µΩ.cm\ °C^{-1}$	4.3×10^{-4}
Thermal conductivity	$W.m^{-1}.°C^{-1}$	12.5
Mean CTE between 0 and 100 °C	$°C^{-1}$	12.5×10^{-6}
Variation of Young's modulus with temperature between 0 and 50 °C	$MPa.\ °C^{-1}$	-400×10^{-6}
Magnetism		Non-magnetic

Mechanical properties

Annealed condition

Softening is achieved by annealing at 1 050 °C for at least 30 minutes followed by rapid cooling, for example in air. The typical mechanical properties are given in the table below:

Properties	Units	Values
Vickers hardness	HV	240
0.2% proof stress	MPa	500
Ultimate tensile stress	MPa	900
Elongation (50mm)	%	50

Influence of cold work and age hardening treatment

The mechanical strength of PHYNOX increases with cold rolling strain. Yield strengths higher than 1800 MPa can be achieved simply by cold working.

Additional strengthening can be obtained by age hardening at 500°C. The influence of aging is negligible in the annealed condition, but increases with the degree of cold work. It is possible in this way to attain UTS levels greater than 2300 MPa. By combining an appropriate amount of cold work with aging, it is possible to adjust the mechanical properties.

For a given strength level, it is preferable to use a combination of cold work and age hardening rather than to use cold work alone. In this way, the stability of the properties with time is greater.

Figures 1 and 2 show the variation of the typical longitudinal tensile properties and hardness with the degree of reduction for strip cold rolled and aged.

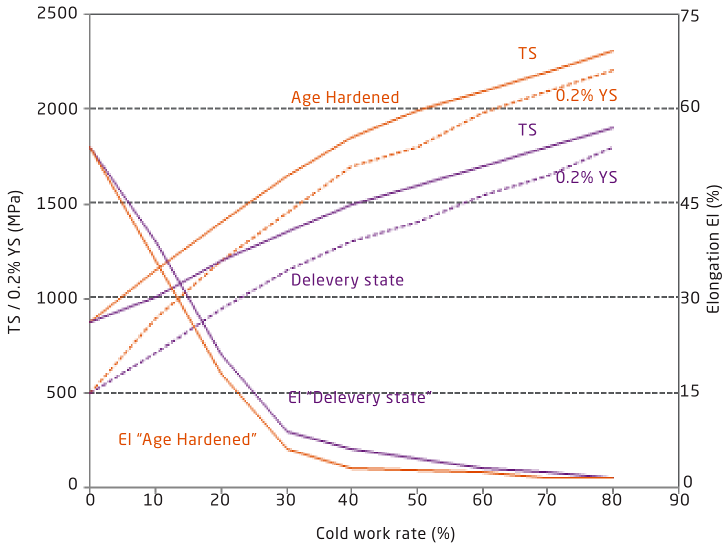

Figure 1: Influence of cold work on 0.2% YS, UTS and elongation

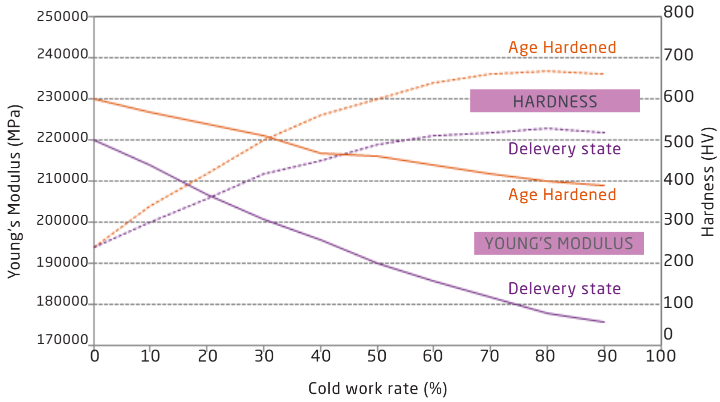

Figure 2: Influence of the degree of cold work on the Young's modulus and hardness

Heat treatment conditions

The standard final aging treatment is 3 hours at 520°C.

Heat treatment in air does not modify the mechanical properties, but impairs the appearance, the metal taking on a pale yellow tinge. Treatments under a vacuum of the order of 10-5 torr or in a neutral atmosphere (e.g. argon) are recommended.

Some atmospheres that are considered to be inert based only on the absence of visible colouring after heat treatment must be used with care. In particular, this is the case for hydrogen atmospheres, which are not recommended, although in certain cases, the properties can be restored by subsequent baking.

Influence of service temperature

Figure 3 shows that, on heating above room temperature, the yield and ultimate tensile strengths of PHYNOX decrease only slowly. This behaviour is particularly interesting compared to that of classical spring steels of the « piano string » type or 18-8 stainless steels. Like the very small cold relaxation, this behaviour is due to the specific crystal structure of Phynox and contributes to the absence of thermal instability. The high strength levels conserved in Phynox at temperatures of the order of 400°C, together with its excellent corrosion resistance, open up a wide range of potential applications.

The variation in elastic modulus with temperature (Figure 4) does not differ significantly from that in other alloys. PHYNOX shows no tendency for brittleness at low temperatures.

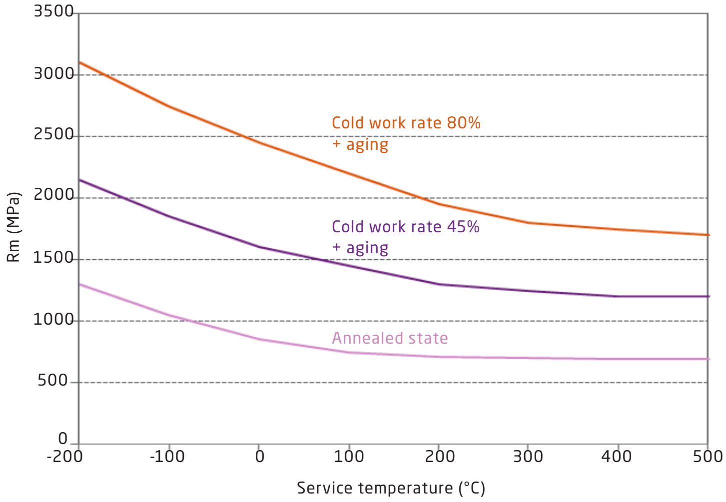

Figure 3: Influence of service temperature on ultimate tensile strength

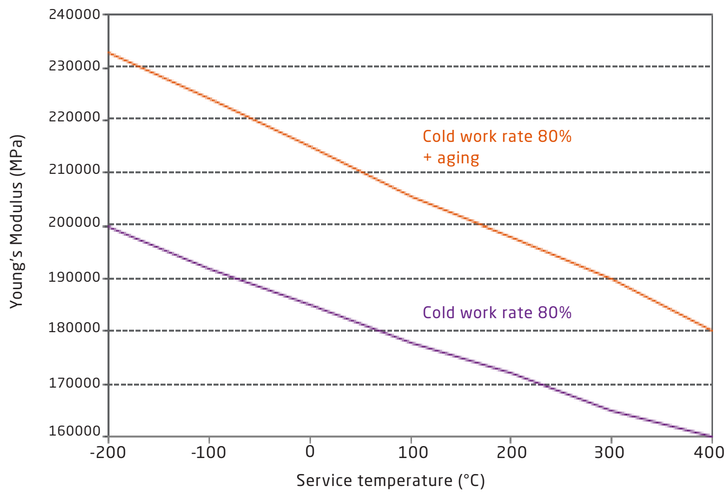

Figure 4: Influence of service temperature on Young's modulus

Corrosion - Resistance

PHYNOX is not sensitive to corrosion by organic acids and shows perfect resistance in salt spray tests. Its behaviour in inorganic acids is greatly superior to that of the best stainless steels.

Furthermore, because of its remarkable passivity in contact with human tissues, PHYNOX is used for artificial bone implants (cast and wrought prostheses).

Technological properties

Machinig and forming

The mechanical properties in the annealed delivery condition are similar to those of other austenitic alloys.

Machining should preferably be performed with carbide tools, since PHYNOX work hardens strongly. A moderate cutting speed should be used, with large rake angles.

Many common machining and forming operations can be carried out in the cold worked condition. In particular, the simple winding of a spring can be carried out for strain levels of up to 85 %. For more complex shaping operations, moderate cold reductions should be chosen.

PHYNOX can be electrochemically machined, certain companies being specialized in this technique.

Welding and Brazing

PHYNOX can be readily welded, in particular by resistance spot welding, by electron beam welding and by argon arc welding. It can also be brazed. However, since age hardening can only be obtained in cold worked regions, this must be taken into account by placing the weld or braze joint in positions where it is not heavily loaded, or by using a discontinuous joint.

Pickling

Apart from mechanical descaling, the oxide film formed during heating in air can be removed by immersing the parts in a boiling aqueous solution containing 5% hydrofluoric acid and 12% nitric acid.

Available Forms

PHYNOX is delivered in the form of strip.

Depending on requirements, the cold rolled strip can be delivered in either the cold worked or annealed conditions, slit to the desired width.

The standard delivery width is less than 100 mm.
Depending on the delivery condition (annealed, lightly, moderately or heavily cold worked), the standard delivery thicknesses are between 0.050 mm and 1.9 mm.

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