Muffle tubes: choose the right material for longer service life

A. Spaghetti

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They are used to shield a product from the environment of the furnace during heat treatment, and create conditions for a more even temperature distribution. In most cases, protective shielding gas is fed into the muffle tube – this can be hydrogen, nitrogen, cracked ammonia or endogas.
Some of these gases are very aggressive and will shorten the life of the tubes significantly. In the annealing furnaces, the temperature is usually between 800 to 1120°C (1472 to 2048 °F), aggressive conditions which often result in a short service life.
If premature failures happen, we recommend careful analysis of the process, which may result in the selection of a more suitable material optimized for your special conditions.
As the value of lost production (and time spent with unplanned maintenance) is so high, a better grade of tube material can have significant economic returns. Our technical and sales teams see this first-hand, working closely with customers to find cost effective solutions to their corrosion issues.

KEYWORDS: MUFFLE – CARBURIZATION – HOT CORROSION – NITRIDATION – SHIELDING GAS – FURNACE – TUBES

Introduction

Sandvik muffle tubes are characterized by long service life and contribute to reduced maintenance costs .
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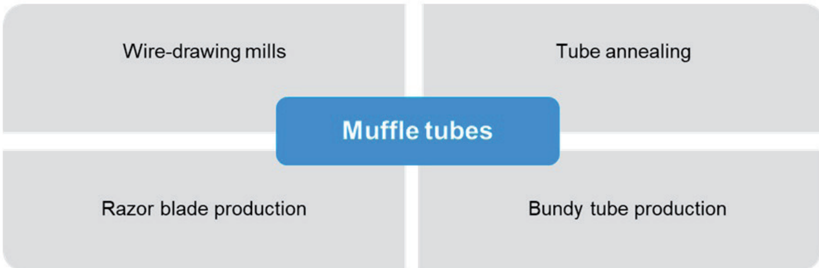

Fig. 1 – Where muffle tubes can be found.

Drawing

During the drawing operation the cross section of a long rod or wire is reduced or changed by pulling it through a die called «draw die». This can also be applied to small diameter stock up to reach wire size down to 0,03 mm.

Drawing is a cold working process and thanks to this it is possible to achieve a final product (wire) with:

- Close dimensional control
- Good surface finish
- Improved mechanical properties such as strength and hardness
- Adaptability to economical batch or mass production

Prior to drawing, the beginning stock must be properly prepared and this can be done through three steps:

(1) Annealing
(2) Cleaning
(3) Pointing

The purpose of annealing is to increase the ductility of the stock to accept deformation during drawing.

As previously mentioned, annealing is sometimes needed between steps in continuous drawing. Cleaning of the stock is required to prevent damage of the work surface and draw die. It involves removal of surface contaminants (e.g., scale and rust) by means of chemical pickling or shot blasting. In some cases, prelubrication of the work surface is accomplished subsequent to cleaning. Pointing involves the reduction in diameter of the starting end of the stock so that it can be inserted through the draw die to start the process. This is usually accomplished by swaging, rolling, or turning. The pointed end of the stock is then gripped by the carriage jaws or other device to initiate the drawing process.

Various other surface defects (such as scratches and die marks) also can result from improper selection of the process parameters, poor lubrication, or poor die condition. Because they undergo non-uniform deformation during drawing, cold-drawn products usually have residual stresses.

Tube annealing

Annealing is a heat treatment that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable. It consists in heating a material to above its recrystallization temperature – maintaining a suitable temperature – cooling (air, water, oil, salt).

In steel, there is a decarburization mechanism that can be described as three distinct events: the reaction at the steel surface, the interstitial diffusion of carbon atoms and the dissolution of carbides within the steel (fig. 2).

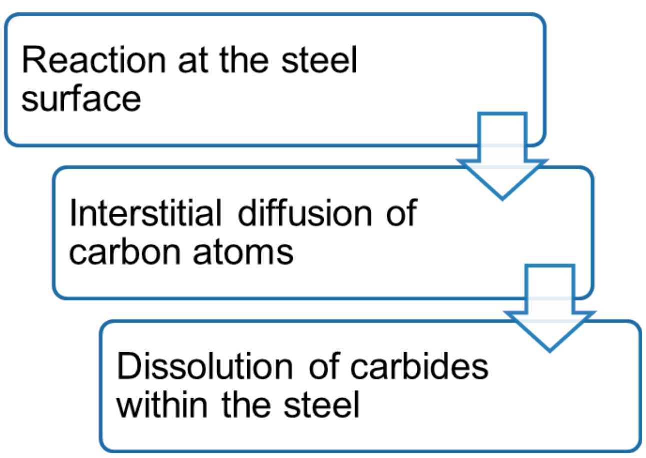

Fig. 2 – Decarburizaton mechanism steps

The three stages of the annealing process that proceed as the temperature of the material is increased are: recovery, recrystallization, and grain growth (fig 3).

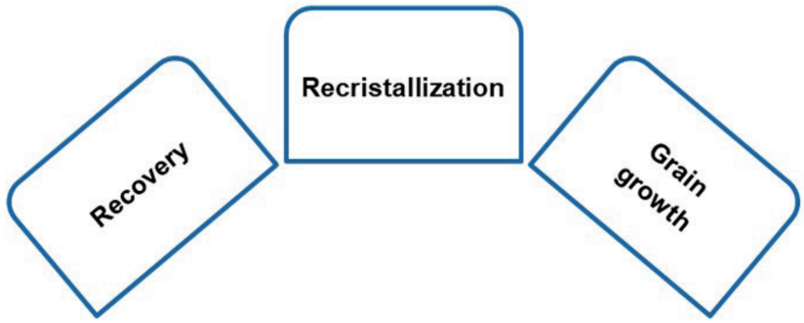

Fig. 3 – Annealing: a three stages process.

The first stage is recovery, and it results in softening of the metal through removal of primarily linear defects called dislocations and the internal stresses they cause. Recovery occurs at the lower temperature stage of all annealing processes and before the appearance of new strain-free grains. The grain size and shape do not change. The second stage is recrystallization, where new strain-free grains nucleate and grow to replace those deformed by internal stresses. If annealing is allowed to continue once recrystallization has completed, then grain growth (the third stage) occurs. In grain growth, the microstructure starts to coarsen and may cause the metal to lose a substantial part of its original strength. This can however be regained with hardening.

The high temperature of annealing may result in oxidation of the metal's surface, resulting in scale. If scale must be avoided, annealing is carried out in a special atmosphere, such as with endothermic gas (a mixture of carbon monoxide, hydrogen gas, and nitrogen gas). Annealing is also carried out in forming gas, a mixture of hydrogen and nitrogen (fig. 4). Continuous annealing furnaces are designed for years of trouble-free service in the processing of wire, rod, strand, strip and tube products. These furnaces are ideally suited for copper, copper alloy, nickel, nickel chrome, titanium, stainless steel and refractory metals. Different temperature ranges are offered to cover a wide variety of applications.

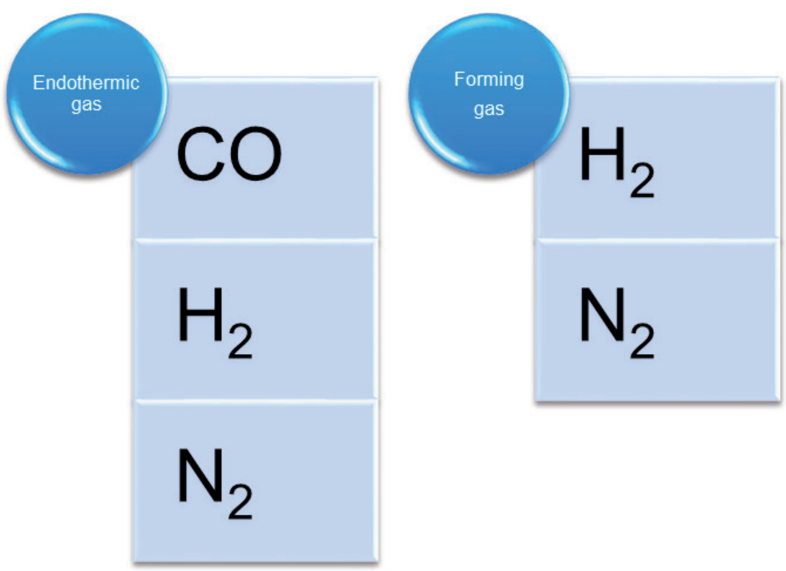

Fig. 4 – How to avoid scaling.

Bundy tubes
Bundy tube, sometimes called Bundy pipe, is type of double-walled low-carbon steel tube manufactured by rolling a copper coated steel strip through 720 degrees and resistance brazing the overlapped seam in a process called Bundywelding. It may be zinc- or terne- coated for corrosion protection. It is used in automotive hydraulic brake lines in cars manufactured in the USA since the 1930s.

Razor blades
Blade manufacturing processes involve mixing and melting of the components in the steel. This mixture undergoes a process known as annealing, which makes the blades stronger. The steel is heated to temperatures of 1,967-2,048°F (1,075-1,120°C), then quenched in water to a temperature between -76- -112° F (-60- -80° C) to harden it. The next step is to temper the steel at a temperature of (482-752°F (250- 400°C).

Muffle tubes product range
Sandvik muffle tube is used in a wide range of industrial applications where a muffle furnace (check) of some type is used as part of the production process. In this case temperatures are up to 1200°C so the key word is heat resistance. When it comes to Sandvik's muffle tube range, some of the key elements are superior heat resistance, excellent corrosion resistance, good material consistency from batch to batch and full traceability. And Sandvik has a strong track record of delivering to some of the most demanding industries and customers in the world.
Some of the key benefits include:
- Premium quality and consistency
- Superior proven heat resistance
- Outstanding corrosion resistance
- Long lifetime of tube reduces maintenance costs
- Full traceability from batch to batch
- Strong Sandvik reference list

All stainless steel materials have protective oxide layers on their surface called Cr2O3 (Chromium Oxide). At room temperature, this protective layer provides a sufficient barrier for diffusion of the gases and protect the tubes to corrode. Unfortunately, when it comes to temperatures higher than 500°C a diffusion mechanism starts with the gases into the metal structure which they start bonding with some of the beneficial elements of the grade (fig. 5).

Fig. 5 – Diffusion mechanism.

Oxygen, carbon and nitrogen compounds tend to bond with chromium though depleting the protective Cr oxide layer. On the other sulfur is easily joinable to Nickel and that is why in case of sulfidation risk it is preferable to use a material very poor or with a lack of Nickel, like a ferritic grade.
Sandvik can produce different types of high temperature resistance alloys that can withstand to all kinds of shielding gases and environments up to 1200°C as per table below (tab. 1)

Tab. 1 – High temperature corrosion resistance materials.

Muffle tube materials (other grades can be supplied upon request)

Sandvik grade (UNS)	Max. operating temp. °C (°F)	Typical enviroments
Sandvik 253 MA* UNS S30815	1100°C (2010°F)	For oxidizing and sulfidizing conditions
Sandvik 353 MA* UNS S35315	1150°C (2100°F)	For oxidizing, carburizing and nitriding conditions as well as in endothermic gas or environments contaning hydrogen gas (H_2)
Sandvik 4C54 UNS S44600	800°C (1470°F)	For oxidizing, sulfdizing conditions as well as for environments contaning hydrogen gas (H_2)
Sanicro™ 61 UNS N06601	1150°C (2100°F)	For oxidizing, nitridig conditions
Sanicro™ 31HT UNS N0881/N08810	1100°C (2010°F)	For carburizing and nitridig conditions

*253 MA and 353 MA are tradmarks owned by Outokumpu Stainless

Material selection
When choosing a material which is able to resist a high temperature corrosive atmosphere, three factors need to be considered (fig. 6):

- Corrosion resistance
- Structure stability
- Creep strength

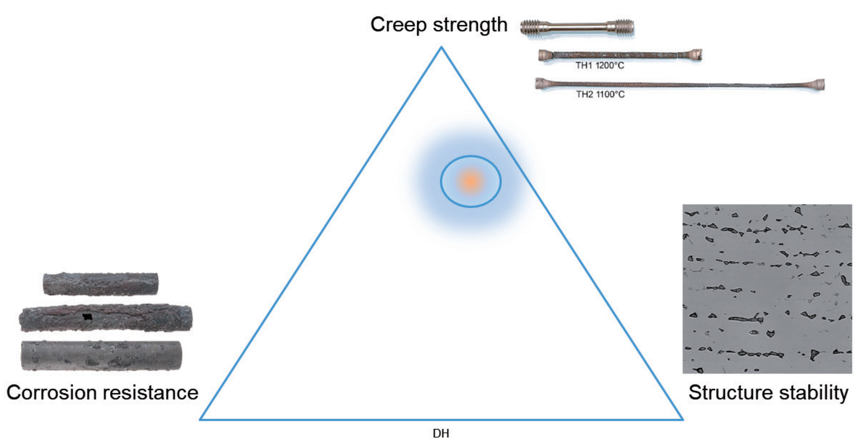

Fig. 6 – Properties to consider in the high temperature world

Corrosion resistance to different environments
The table below shows a comparison of some grades at different and most common atmospheres.

Tab. 2 – Comparsion between some grades at different atmospheres

A comparison between Sandvik high-temperature materials with TP 304H

Sandvik grade	In air	Oxidizing sulfur	Reducing sulfur	Carburizing	Nitriding
304H	0	0	0	0	0
321H	0	0	0	0	0
347H	0	0	0	0	0
316H	0	0	0	0	0
309	++	++	+	+	++(**)
310H*	+++	++	0	++	++
253 MA*	++++	+++		+++	++(**)
353 MA*	++++	+	0	++++	++++
Sanicro™ 31HT*	++	+	0	+++	+++
Sanicro™ 61	++++	0	-	+	++
Sanicro™ 70	+++	0	-	+	++++
4C54*	++++	+++	++++	-	-
2C48	+++	+++	+++	-	-

* Sandvik stock standard
** In low oxygen potential (<100ppm O2), nitriding may occur
*** In low dew point (<20°C), severe nitriding may occur
0 = reference value + = superior to – = inferior to

The main atmosphere used in muffle furnaces are:
- Hydrogen up to 1250°C
- Nitrogen up to 1150°C
- Cracked ammonia up to 1100°C
- Endogas up to 1150°C
- Air up to 1250°C

With each of them it is important to carefully select the best grade in order to fulfill the requested performances.
Sandvik Sanicro 31HT is often used in environments with cracked ammonia, which is the most aggressive environment in this application. It causes rapid nitriding of the tube material, which leads to a loss of the mechanical strength. By selecting an alloy with higher nickel content, it is possible to extend the service life. In this environment, Sandvik Sanicro 61 offers much longer service life.
Sandvik Sanicro 31HT is a highly suitable material where pure nitrogen or a gas mixture of nitrogen and hydrogen is used. Nitrogen is a less severe environment than cracked ammonia. The endogas will cause a rapid carburization, which also reduces the muffle tube's mechanical strength. In these conditions, Sandvik 353 MA is the most cost-effective material. For severely carburizing conditions, Kanthal APM or APMT is a better choice than Sandvik 353 MA. Hydrogen is a less aggressive environment. In these conditions, the most cost-effective material is Sandvik 253 MA, followed by Sandvik Sanicro 31HT.
Sandvik 4C54 is a cost effective choice for annealing of carbon steel as it is done in a lower temperature range. Certain operational conditions will shorten the service life. Residuals, such as hydrocarbons, soap or drawing powder can increase the risk of corrosion. Frequent temperature cycling will also shorten the service life. If premature failures happen, a careful analysis of the process is recommended, which may result in the selection of a more suitable material optimized for any special conditions.
The figure below (fig. 7) shows the recommended operating temperatures in air for some of the main grades.

Structural stability
These materials are made to work at high temperature so there are some ranges that should be avoided since they can encounter in the precipitation/formation of some harmful intermetallic and fragile phases as shown in figure 8.

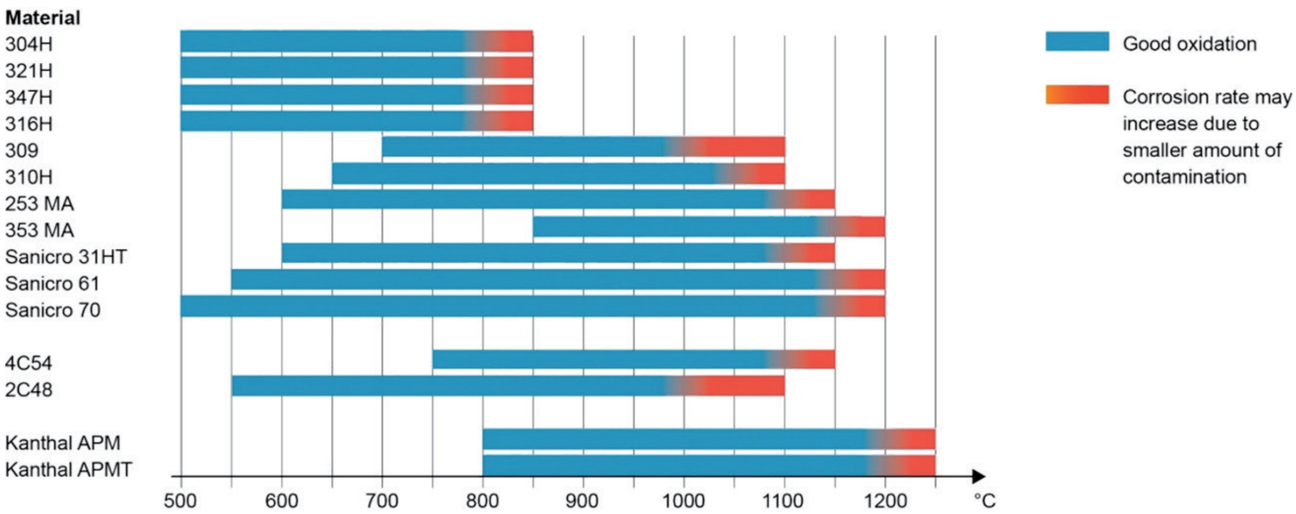

Fig. 7 – Recommended operating temperature in air

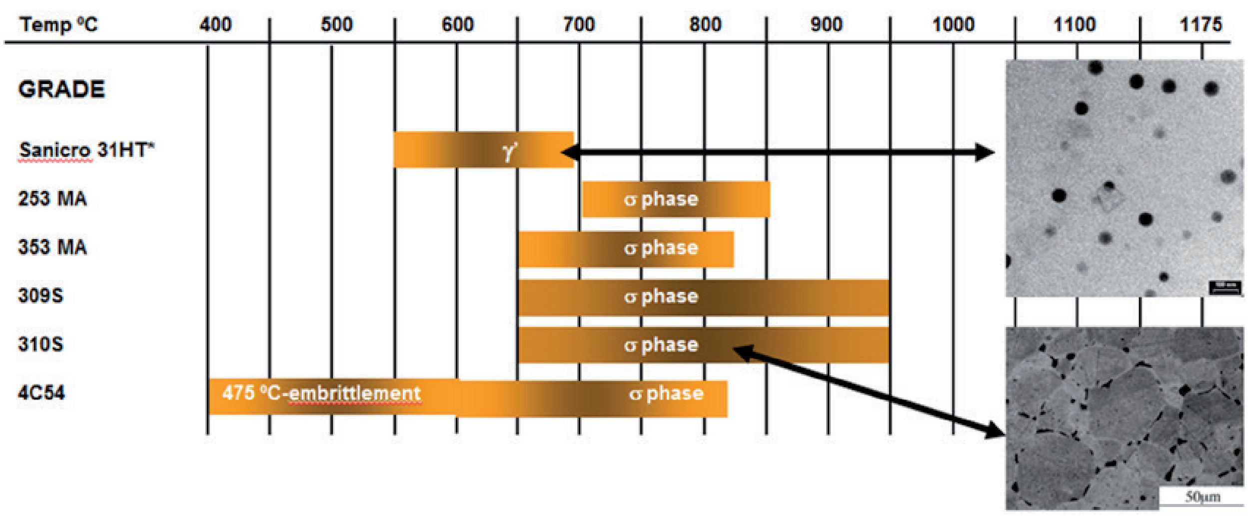

Fig. 8 – ranges of temperature to avoid due to precipitation of intermetallic phases

For example the Sanicro 31HT can form gamma prime phase while all the others form the well known brittle sigma phase. 4C54, a ferritic grade, can also have issues due to the phenomena of the 475°C-embrittlement.
The formation of these phases happen with different velocities based on the material as shown in the TTT diagram in figure 9.

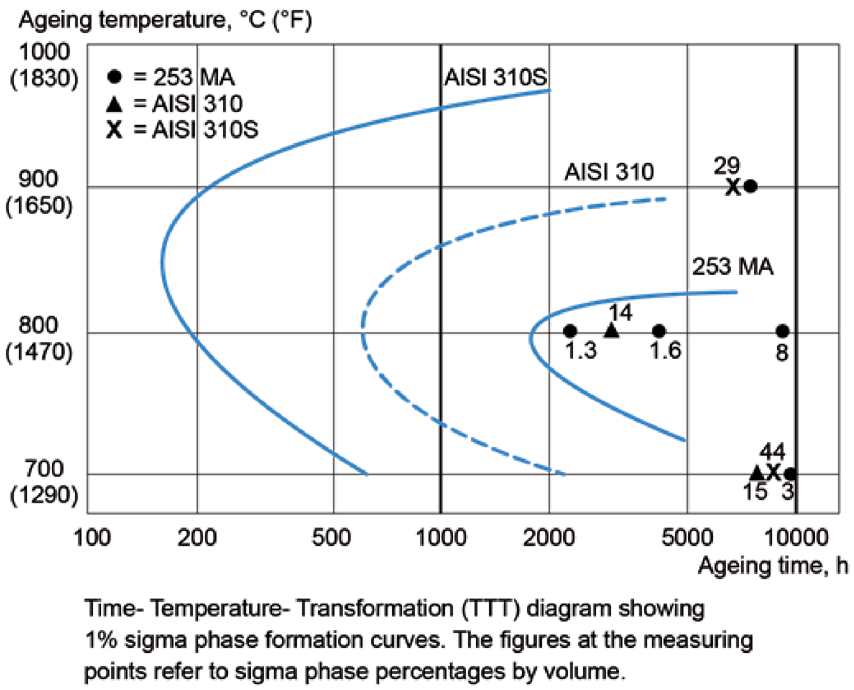

Fig. 9 – TT Diagram showing 1% sigma phase formation curves.

Within the precipitation ranges for the different phases it is important to consider that 1% sigma phase is precipitated at 800°C for 353MA after 7000 h, for 253MA after 2000 h, and for 310 and 309 after less than 200 h. 4C54 precipitates 1% sigma phase at 650°C after less than 200 h.
From fig. 9 the mechanism and the different kinetics are even clearer.

Creep strength
Creep strength is important in case there is the risk of deformation of the material at high temperature.
As can be seen the ferrtic grade is the less resistant to creep while SAN31HT and the MA grades seem to have better performances.

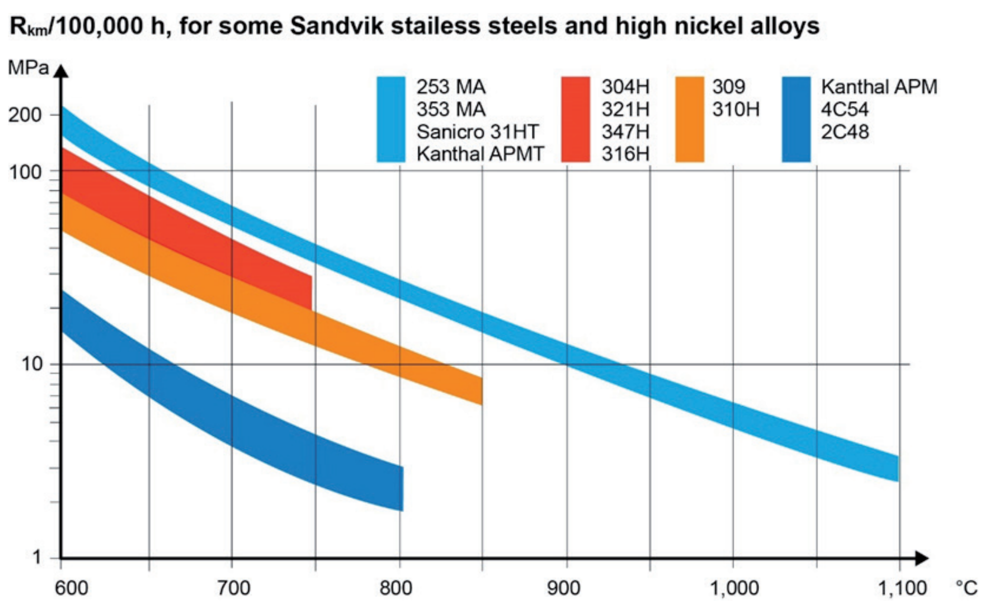

Fig. 10 – Creep rupture strength.

Summary and conclusions

Muffle furnaces are most often used in wire drawing mills and in bundy tube production, but they can also be found in other applications such as razor blade production and tube annealing. They are used to shield a product from the environment of the furnace during heat treatment, and to create conditions for a more even temperature distribution. In most cases, some protective gas is fed into the muffle tube. This shielding gas can be hydrogen, nitrogen, cracked ammonia or endogas ($CO + H_2$). Some of these gases are very aggressive and will shorten the life of the muffle tubes significantly.

In some annealing furnaces, the temperature can reach above 1,200°C, but temperatures between 800 and 1,120°C are most common. These high temperatures often result in a short service life, leading to frequent stoppages for maintenance and muffle tube replacements. As the value of lost production is high, the decision to select a better grade (tube material) will pay off in the long run.

Sandvik Sanicro 31HT is often used in environments with cracked ammonia, which is the most aggressive environment in this application. It causes rapid nitriding of the tube material, which leads to a loss of the mechanical strength. By selecting an alloy with higher nickel content, you can extend the service life. In this environment, Sandvik Sanicro 61 offers much longer service life.

Sandvik Sanicro 31HT is recommended as a suitable material where pure nitrogen or a gas mixture of nitrogen and hydrogen is used. Nitrogen is a less severe environment than cracked ammonia. The endogas will cause a rapid carburization, which also reduces the muffle tube's mechanical strength. In these conditions, Sandvik 353 MA is the most cost-effective material. For severely carburizing conditions, Kanthal APM or APMT is a better choice than Sandvik 353 MA. Hydrogen is a less aggressive environment. In these conditions, the most cost-effective material is Sandvik 253 MA, followed by Sandvik Sanicro 31HT. Sandvik 4C54 is a cost-effective choice for annealing of carbon steel as it is carried out in a lower temperature range.

Certain operational conditions will shorten the service life. Residuals, such as hydrocarbons, soap or drawing powder, can increase the risk of corrosion. Frequent temperature cycling will also shorten the service life. If premature failures happen, we recommend a careful analysis of the process, which may result in the selection of a more suitable material optimized for your special conditions.

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