Hardening and tempering of fasteners

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Today's high quality requirements together with economic constraints have let the development of fasteners' furnace technology to continuous plants for mass-production with belt-type furnaces resulting as the dominant design. The article describes in general the process of hardening and tempering and the plant technology commonly employed in modern fastener industry. Emphasize is put on precise process monitoring of the mass bulk flow with regard to the uniform final properties like tensile strength and toughness of the single fastener.

Fig. 1: Partial view on a hardening and tempering line with a nominal throughput of 2000 kg/h

Hardening and tempering is arguably the most important heat treatment in the fastener industry. For automotive safety parts this important production step is being almost always employed. Basis for the heat treatment of fasteners is the standard EN ISO 898-1 that prescribes a homogenous hardened and tempered steel structure. Carbon contents of 0,25% to 0,35% result in best values for combined tensile strength and toughness both for non- and low-alloyed steels. A tensile strength ranging from 800 to 1300 N/mm² may also be achieved under certain conditions and with limited flexibility without final heat treatment with e.g. cold forging and ageing or employing micro alloys but these have had limited application up to now.

Furnace technology

Industries' high requirements for fastener characteristics demand a specially designed furnace, reliable plant technology, field experience and knowledge of physical and metallurgical process parameters and their influence on heat treatment results. This is especially true for mass-produced high-grade fasteners with diameters ranging from smaller than 2 to bigger than 50 mm. Generally it's expected that every single piece, without having any defect at all, will have defined properties with small dispersions of hardness, tensile strength, toughness, fatigue strength among others.

The furnace plant design targets may be summed up as

- highest process capability within narrow tolerance bands and reliability of plant parameters
- plant availability and productivity
- lowest life cycle costs regarding
  - operating: media consumption
  - service life: preventive maintenance
- minimum environmental impact

To achieve these objectives fasteners are nowadays chiefly heat-treated in continuous furnace lines tailored to customers' needs and possibly geared towards an almost identical temperature – ambient gas/fluid impact on the single pieces in the bulk flow. The characteristic statistic values describing the degree to which the required properties are satisfied are Cm(k) and Cp(k) for machine and process respectively, with the subscript k further indicating the position of the scatter band between the specified tolerance limits. The k values can most times be centered adapting e.g. the tempering temperature. A common accepted value for Cm(k) or Cp(k) is > 1,67. The tolerance bands for the tensile strength prescribed for the various grades in EN ISO 898-1 are often further reduced to 50 MPA, especially by the automotive industry. Exactly observing the theoretic temperature curves of hardening and tempering becomes secondary to the homogenous distribution of the properties of the single fastener and the continuous monitoring of parameters like temperature, recirculation flow and protective gas composition is crucial to production.

Batch type furnaces due to their economic disadvantages with large production runs are used for special applications like positioning with long and slim fasteners that are subject to bending or for flexibility demands with small charges.

A complete belt furnace line installation for hardening and tempering is shown in **Fig. 1**. It typically comprises in sequence a container's unloading station, a prewashing and dephophating machine, the hardening furnace, an oil quench, a postwasher, the (bright) tempering furnace with subsequent soluble oil cooling and a container refilling station.

Continuously operating furnace lines for fasteners of the belt type can be divided into

- cast link belt type furnaces employed for the hardening and tempering of more rugged fasteners from M5 to M 48 with throughputs from 500 to 3000 kg/h (**Fig. 2**).

  Further characteristics of these furnaces are: the rugged belt can be charged approx. twice as much as a wire mesh belt and the furnace entrance may be closed by a protective gas lock both of which reduce considerably the heat and protective gas consumption; the furnace is usually gas - heated with recuperative ceramic or cast steel radiation tubes, it's economically best suited for large-scale production with big heat treatment lots

- wire mesh belt type continuous furnace lines for fasteners from approx. M2 to M24 with smaller throughputs from approx. 10 to 1000 kg/h (**Fig. 3**).

  Further characteristics: appropriate also for smaller fasteners, the belt charging can be monitored easily from the outside, the belt drive is made as a moving honeycomb hearth plate or on support rollers, electric heating for smaller throughputs

The continuous washing machines are available as drum and conveyor version for akaline cleaning of the fasteners before and after hardening. The prewashing comprises also a dephosphating stage required for grade 12.9 by EN ISO 898-1 since the phosphate stemming from the wire coating may result in dangerous surface decarburization. The postwasher, apart from cleaning off the quench oil, should also guarantee that the fasteners are properly dried before entering the tempering furnace.

Hardening

Hardening temperatures for fasteners range normally from 880 to 900°C. The purposes of the furnace is to homogenously austenitize and dissolve the ferrous and alloy carbides in the steel as carbides or lower carbon content in the austenitic phase deteriorate the hardness of the fasteners upon the subsequent quenching. The process is carried out under neutral endothermic protective atmosphere enriched with either natural gas or propane as correctives. Alternatively nitrogen with methanol cracked inside the furnace proper might be used. The control of the carbon potential to adapt it to the fastener steels' carbon content quality is done for both processes continuously with sampling tools like Lambda or oxygen probes.

The time for austenitizing and carbide dissolving with cold formed low-alloy fasteners varies between approx. 10 and 15 minutes with previous good annealing for easier cold forming prolonging this time. Add to this the heating up and soaking times with bigger diameters and higher bulk heights on the belt requiring more time. This implies that the throughput ≈ bulk height / furnace residence time depends on the fastener dimension, bulk density and temperature distribution in the furnace proper. An example of a measured temperature curve of fasteners and derived resident times in a hardening furnace is shown in **Fig. 4**.

Fig. 2: Cast link belt furnace for a production rate of 3000 kg/h with opened maintenance front door

The drop chute for the transfer of the fasteners into the quench bath is heated to prevent the austenitized fasteners from cooling prematurely and remaining soft. Its' quenchant curtain hinders rising vapor from entering the furnace proper. Above it on the inside the drop shaft a gas suction device further shields off the protective atmosphere.

The martensite hardening of high-grade fasteners from boron or higher alloyed steel is done in mineral quench oil to achieve the critical cooling speed necessary for the austenitic transformation and on the other hand to avoid bending or even cracking. The falling depth depends primarily on the fasteners' diameter, then on its alloy content. The falling speed in the quenchant varies from 1 to 2 m/s nearly independently of the fasteners' size.

The discharge is almost always done by a belt conveyor with bolted-on flights, with smaller fasteners also being extracted by means of a bucket-chain or magnetic conveyor.

Since most fasteners due to heat transfer physics need rather a long time to cool down they hit the belt being still in their soft, red-incandescent, austenitic state. The time e.g. for a screw M16 of 20MnB4 steel to cool down to 500°C is approx. 10s. This means that the minimum quenching speed according to the steel quality must be fulfilled when hitting the belt by sufficient delivery of quenchant into the impact area. If the belt is running too slowly with the aim to extract the fasteners rather cold to avoid oil smoke the fasteners might amass on the flights and worsen the quenching speed for the single fastener then lacking circulation flow. The quenching technique supposes that the fasteners' alloy content is high enough to reach the critical quenching speed in the fasteners' total section. For big bolts up to M48 alloys like 34CrNiMo6 have

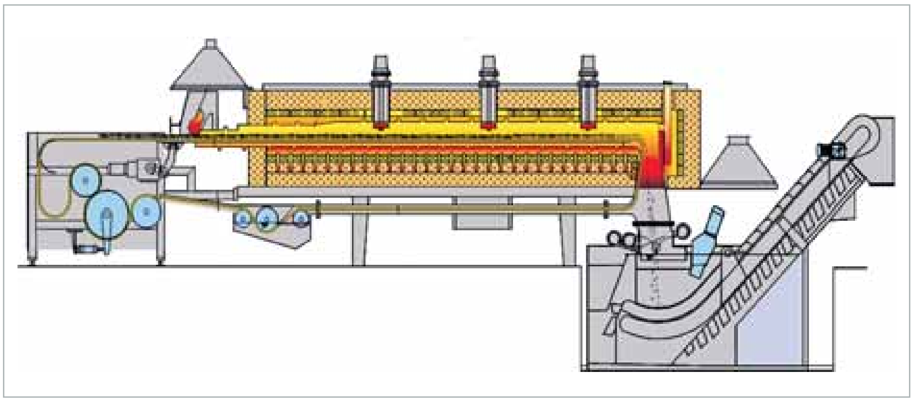

Fig. 3: Section of a wire mesh belt hardening furnace with integrated oil quench for a throughput of 500 kg/h, fig. courtesy of Safed

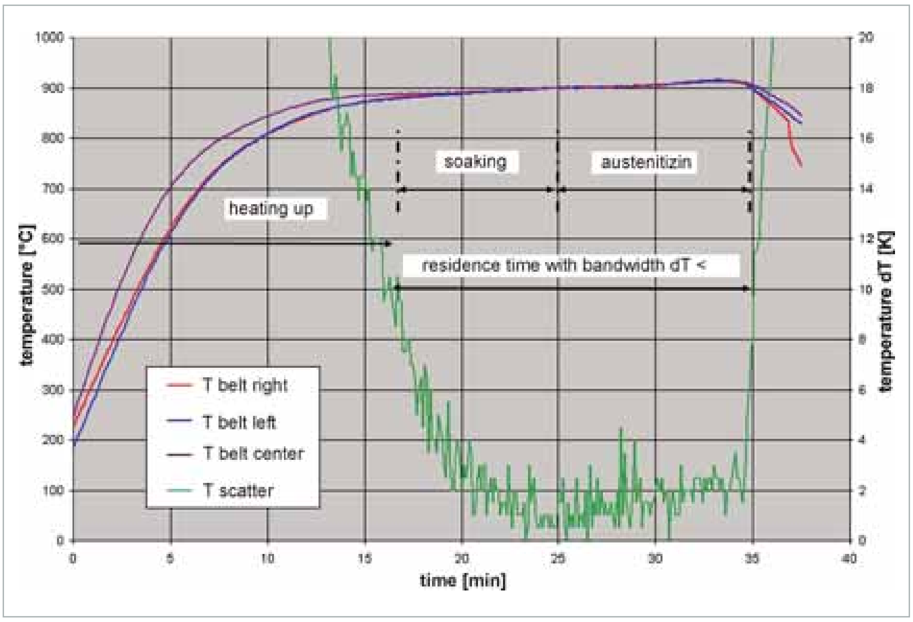

Fig. 4: Thermocouple drag test of temperature uniformity in a hardening furnace with 1000 kg/h

to be used to harden also the core. The risk with big bolts is cracking due to the high inner tensions by heat transfer during quenching. The known hardness of the fasteners depending on their carbon percentage with 99.9% martensite can easily be used to confirm the completeness of austenite transformation by taking samples during production.

Tempering

The tempering determines the final properties of the fasteners. The tempering temperature and time of approx. 60 to 120 min are the parameters for final tensile strength and toughness. As a rule of thumb the higher the temperature and the longer the dwelling time of the fasteners in the tempering furnace the lower will be the tensile strength and the higher the toughness values. The disintegration speed of the martensite is also an exponential function of the still non – transformed martensite, so that the times both for heating up and dwelling on temperature are summed up.

To get results within narrow tolerance bands it's not sufficient to rely on set recipes for carbon / alloy content and fastener grade. The metallurgic analysis (18 elements) for each heat treatment lot has to be taken for setting and fine-tuning of the furnace parameters. Another important quality determining factor is the uniform distribution of the fasteners on the belt. If they pile up heating-up and soaking times can vary so that final mechanical properties scatter strongly.

The tempering furnaces are also executed as wire mesh belt or cast link belt conveyor types, matched to the throughput of the hardening furnace. The throughput is again a function of the bulk density. Since the heat transfer in the typical tempering range from 350°C to 570°C depends mainly on the convection imparted by the axial cyclones or fans a lower bulk density i.e. slim fasteners allows for higher bulk heights with fasteners' final properties remaining constant. To achieve the powerful atmosphere recirculation the furnace is divided into multiple zones and precisely controlled.

Alternatively to the air or nitrogen atmosphere the so-called bright tempering process with protective gas is being used. The aim is to reduce the risk of hydrogen embrittlement. Since the modern zinc lamellar surface coatings require a bright surface, i.e. not even permitting tempering colors the pickling normally done to reduce the oxide layer as a surface preparation may be reduced or even left out.

After tempering the fasteners are cooled down in a soluble oil bath with falling depths in the liquid of around 1 m. In most cases the desired surface property for fasteners is still blackened / oiled. The pores in the Fe_3O_4 oxide layer of 1-3 µm thickness are being filled with oil residues. Condition for this blackening is a tempering temperature of min 400°C. The resulting surface protects sufficiently against corrosion during storage of the fasteners.

Common problems arising with the heat treatment of fasteners

The mass bulk production of fasteners entails specific problems that must be taken care of and minimized during design and operation of the continuous furnace plants. Most important are

- damages on threads due to handling of the bulk flow especially in the container loading station and pre-washing machine when fasteners are still soft. Fine-threading might be done only after the heat-treatment.
- parts mixing of different heat treatment lots on the belts
- bending of fasteners with a length/diameter ratio of approx. > 12. These fasteners must be straightened afterwards or heat-treated on a rack in batch type furnaces
- contamination by alkaline deposits of the high temperature furnace proper and its influence on the heat treated fasteners. This can be reduced by a double-rinsing stage after dephophating in the pre-washing machine and employing a triple water cascade with fresh water directly sprayed on the fasteners in the final washing stage.

Conclusion

As discussed above the challenge in the heat-treatment of fasteners lies chiefly in the mass – production requiring that each single piece exists the process with the same values of final tensile strength and toughness. Today's furnace developments are aimed at reducing the statistical tolerance bands of these properties. ■

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