Process technology and plant design for bainite hardening

H. Altena, K. Buchner

Bainite hardening or austempering is a commonly used process especially in the bearing industry. In the last years an increased interest in austempering processes for different applications can be found. The first part of the presentation deals with the metallurgical requirements, the process technologies and the materials which can be used for an austempering process. Furthermore the advantages, but also the restrictions of the process are pointed out. Depending on the requirements, batch type furnaces or continuous plants can be used. The furnace design with regard to salt bath quenching and the most important factors influencing the parts' quality are explained. In the second part some practical applications of bainite hardening, the processes and the required furnace technologies are shown with regard to the specific heat treatment demands of the austempering products.

KEYWORDS: BAINITE HARDENING - FURNACE TECHNOLOGY - SALT BATH - SEALED QUENCH FURNACE - ROLLER HEARTH FURNACE - PUSHER FURNACE - CONVEYOR BELT FURNACE

INTRODUCTION

Traditionally bainite hardening was always combined with salt bath technology. About 25 years ago, when the old salt bath technology lost its' importance because of dirt, safety and ecological reasons, the interest in bainite hardening was decreasing, too.

Times have changed, modern salt bath installations are completely capsuled and safe. The composition of salts was adapted to fulfil the ecological requirements and recycling of the used salts can be carried out.

This might be the reason that bainite hardening or austempering processes start to gain increased interest, besides of the mainly used applications in the bearing industry. Furthermore a lot of research is done to analyse the advantages of the process for different materials and applications. Subsequent the principles of the austempering process, suitable materials and applications will be pointed out.

Herwig Altena, Klaus Buchner
Aichelin Holding GmbH,
A-2340 Mödling, Fabriksgasse 3, Austria

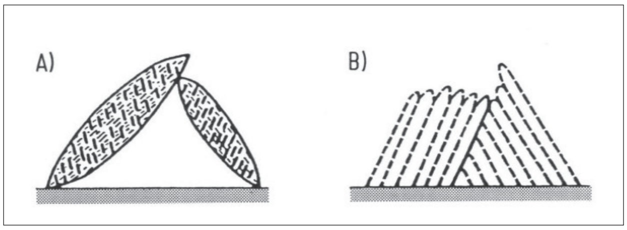
Paper presented at European Conference on Heat Treatments ECHT 2015 and 22nd IFHTSE Congress, Venice 20-22 May 2015 - organised by AIM

METALLURGICAL FUNDAMENTALS

Heat treatment process and structure of the materials

The structure of bainite can vary in a wide range, depending on the temperature of the salt bath. Depending on the temperature, two different structures can be achieved: the "upper" and the "lower" bainite (Fig. 1).

Fig. 1 - Structure of bainite needles,
A) lower bainite, B) upper bainite structure [1]



At upper temperature of the transformation range, it resembles pearlite. Initial nuclei are ferrite which is coherent with the austenite matrix. Cementite then precipitates from the carbon-enriched layer of austenite, allowing further growth of the ferrite. The carbides tend to lie parallel to the long axis of the bainite needle to form the typical open feathery structure of upper bainite [1, 2].

At low temperatures it appears as a black needle-like structure resembling martensite and is known as lower bainite. In lower bainite, the ferrite needles become thinner and the carbide platelets become smaller and more closely spaced. The carbide platelets are usually oriented at an angle to the long axis of the ferrite needles, rather than parallel.

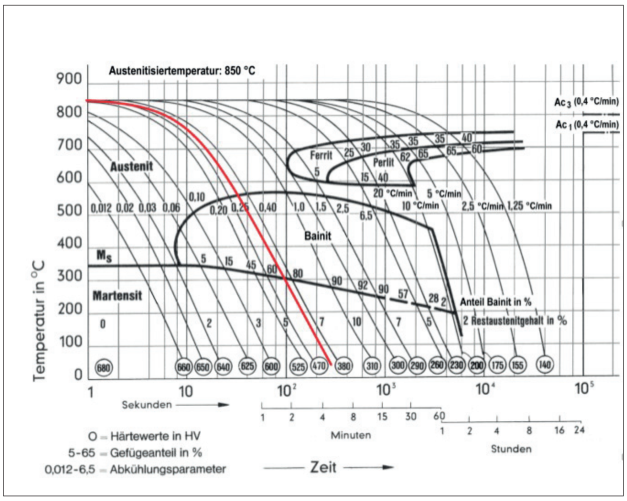
The hardness of bainite varies from about 40 HRc for upper bainite to about Rockwell 60 HRc for lower bainite. This increase in hardness, as with pearlite, is a reflection of the decrease in size and spacing of the carbide platelets as the transformation temperature decreases [1, 2].

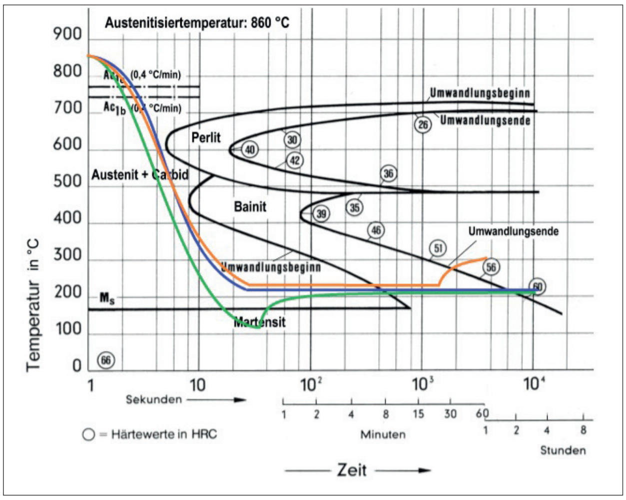
Cooling strategies for bainite hardening

Possible cooling rates are influenced by many parameters, such as quenching speed of the salt, the salt bath temperature, agitation of the quenching media, dimensions and weight of the load (or the parts), loading density, etc. Fig. 2 shows a continuous (A) and an isothermal TTT-diagram (B) of SAE 52100 (= 100Cr6), the typical bearing steel. Depending on the steel grade, for bigger parts or higher wall thickness the formation of bainite cannot be avoided by continuous quenching, leading to an inhomogeneous structure (Fig. 2A). This structure is caused by different types of bainite, which develop during continuous quenching.

Fig. 2 - Possible cooling strategies for bainite hardening: Continuous cooling (red), isothermal cooling with dwell time for desired hardness and structure (blue) and multi-stage process (green, orange) [3]

A) B)





To achieve a homogeneous structure, the material grade and the quenching ability of the quenching bath must fit to the load to allow the cooling curves to pass the pearlite and the bainite "nose" by isothermal quenching. As you can see from Fig. 2B, the dwell time for fully finishing the bainitic structure could become very long. This time is increasing with increasing alloying content of the material, especially with Nickel or Molybdenum, and by lowering the salt bath temperature. To shorten the dwell time, two different strategies can be chosen: to increase the dwell temperature at the end of the bainitization or to quench the parts slightly below martensite start, create some martensite seeds and then follow the dwell time at bainitization temperature [3].

Table 1 gives an example for reducing the dwell time for bainite hardening of bearing steels, which were austenized at 845 - 860 °C. The variation of the austempering temperature can shorten the dwell time for 60 up to 70%:

Tab. 1 - Cooling strategies for bainite hardening of bearing steel

Steel type	Temperature [°C]	Duration [h]	Hardness [HRC]
100 Cr6	225	7,5	60,1
100 Cr6	210	2	
	250	1	60,0
100 CrMo 7 3	210	33	60,1
100 CrMo 7 3	210	9	
	250	1	59,9

Material for bainite hardening

As mentioned before, the material grade must be chosen in combination with the parts geometry. An alloy with sufficient hardenability is needed. However, the good hardenability should not cause too long dwell times - a difficult compromise. Usually bearing steels, tempering steels or case hardening steels are used. A special application is the austempering of cast iron, called ADI (austempered ductile iron).

ADVANTAGES AND DISADVANTAGES OF BAINITE HARDENING

The advantages or disadvantages of the process might vary in dependence with a special application, however, some general rules can be listed:

As mentioned before, bainite consist of ferrite with fine carbide precipitations.

Therefore the changes in volume are reduced, followed by

a reduced size of the crystal lattice, which leads to a reduced distortion of the parts. Furthermore, in most applications the tempering process can be saved.
The bainitic material shows desirable compressive stresses at the surface, which are significantly higher than with martensitic hardening. Further advantages are higher yield strength with same hardness as tempered steel, higher tensile stress and improved notch impact strength. Finally, the residual austenite is lower than with martensitic hardening.
As a disadvantage it has to be mentioned, that the dwell time might be very long and therefore the process might get uneconomical. Furthermore the process parameters have to be carefully adjusted to the parts geometry and the material. Finally the austempered material usually does not achieve the same maximum hardness as martensitic hardened material.

FURNACE TECHNOLOGY

Bainite hardening can be carried out both in chamber furnaces and in continuous lines. Chamber furnaces can be executed with open or integrated salt bath as a sealed quench furnace. The open, not gas-tight salt bath is executed with an insulated and heated hood and therefore it looks quite similar to the gas-tight execution. However, the high temperature chamber has a flame curtain, which has to be passed by the load, when it is been transported to the air filled hood. When the load has reached its' end position in the hood, it is immediately lowered into the open salt bath below. The integrated solution allows holding the load in a neutral atmosphere when being transported from the heated zone to the salt bath.
For higher throughput capacity continuous furnaces, mainly roller hearth furnaces, conveyor belt furnaces and pusher furnaces can be used. In chapter 4 you will find some practical applications of batch type applications and continuous lines.
Usually bainite hardening is a neutral hardening process, therefore the carrier gas has to avoid any carburization or decarburization of the material. For bearings, which are usually made of 100Cr6 materials group, the gasifying can be done with

- nitrogen + hydrocarbons, preferably propane,
- nitrogen/methanol + hydrocarbons, preferably propane or
- endothermic gas + hydrocarbons, preferably propane.

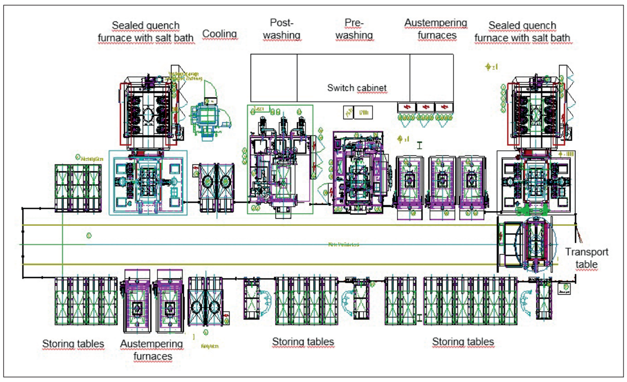
PRACTICAL APPLICATIONS

The following four applications show the variety of targets and solutions for bainite hardening. Depending on the specific requests, the furnace has to be individually designed or adapted to fulfil the customers' demands.

Sealed quench furnace line

Target was the bainitic and martensitic hardening of bearings, additionally to allow gas carburizing and carbonitriding processes in the same furnace line with a load weight up to 1000 kg. To execute this variety of different processes, a chamber furnace line is always the best joice.
So a sealed quench furnace line was realized, consisting of 2 sealed quench furnaces and 5 tempering furnaces for preheating and tempering to fulfil the demands. The transfer table was insulated (heated as an option) and an execution with open salt bath quenching was applied. An integrated salt bath with gas-tight vestibule was offered as an option. The layout of the plant can be seen in Fig. 3.

Fig. 3 - Plant layout of a sealed quench furnace line



Roller hearth furnace line

To fulfil a throughput capacity of 4000 kg/h for bainite hardening of 100Cr6 bearings a continuous line was required. Furthermore the customer required a variation of austenitizing temperature and quenching parameters according to the ring size and type.
To fulfil the demands, 2 mirrored roller hearth furnaces were designed with a joint salt bath management system. The transport was executed via ceramic rollers, the load size was 1350 x 1400 mm. A big salt bath with 64 positions for bainite transformation was needed. Fig. 4 shows the layout of the plant. In Fig. 5 the austenitizing furnace can be seen.

Fig. 4 - Plant layout of a roller hearth furnace line

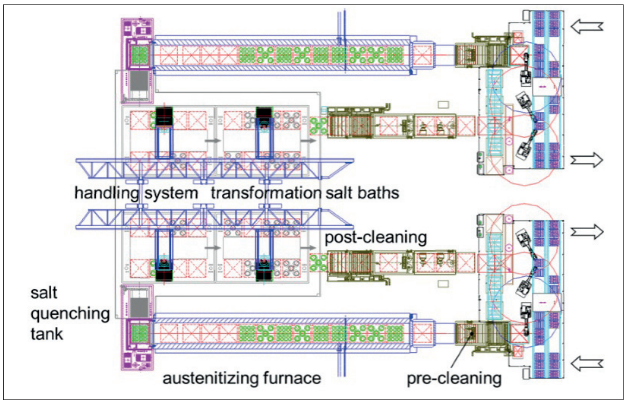
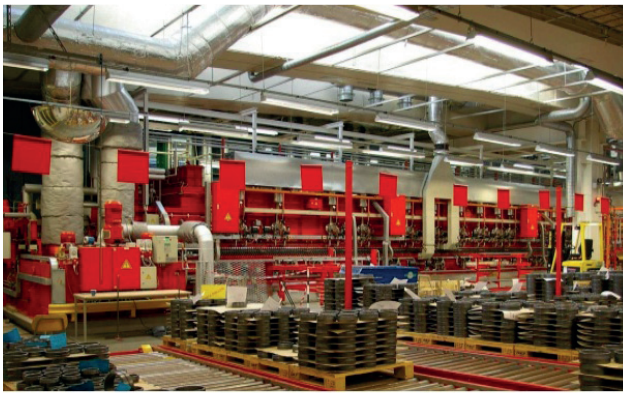
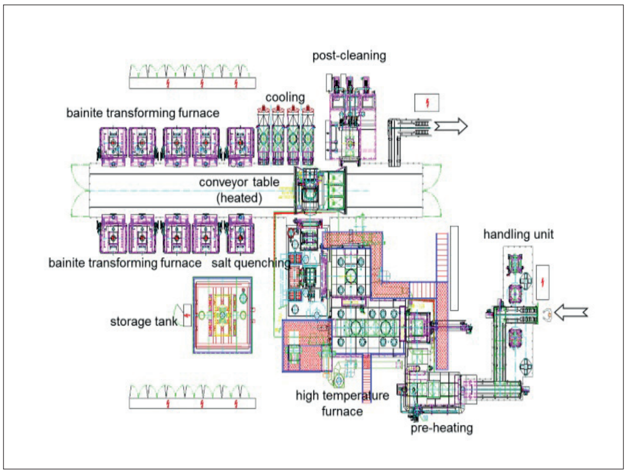


Fig. 5 - Austenitizing furnace of a roller hearth furnace line



Pusher furnace
For a medium production capacity of 100Cr6 parts which have to be bainite hardened, a pusher furnace design can be shown as an alternative. The layout shows a preheating furnace, a pusher, a heated conveyor table and 10 tempering furnaces for bainite transformation (Fig. 6). In this application the salt bath is used just for quenching plus temperature stabilization; the further bainite transformation is carried out in separate tempering furnaces.

Fig. 6 - Plant layout of a pusher furnace line



Conveyor belt furnace line
In the last example it can be seen, how market pull in the automotive industry causes changes in the heat treatment technology. Downsizing of engines and weight reduction is a big target in the automotive industry. To reduce weight even every screw is taken into account, therefore ultra-high strength screws get high importance. The motivation is to increase the strength of screws from class 12.9 to class 14.8 (and up to 16.8) without changing the ductility according with class 12.9.
To fulfil this task, bainite hardening of the screws was applied. Fig. 7 shows the improvement in tensile strength in comparison with martensitic hardening and tempering. Fig. 8 shows the conveyor belt furnace with salt bath and washers.

Fig. 7 - Advantage of bainite hardening over martensitic hardening [4]

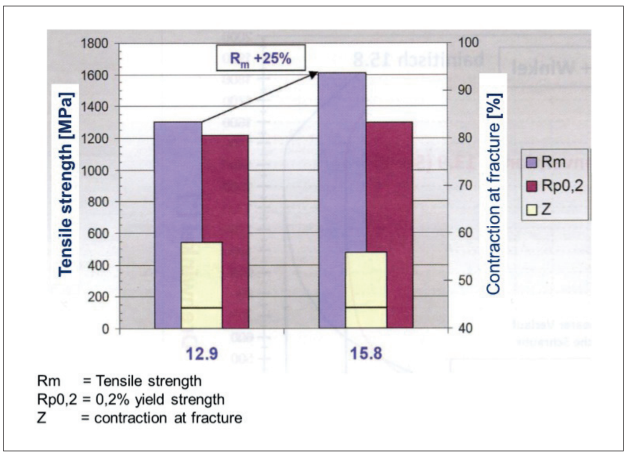


Fig. 8 - Conveyor belt furnace with salt bath and washers

CONCLUSION
In the last years an increased interest in bainite hardening processes for different
applications can be found. Besides the applications in the bearing industry, where salt bath quenching is state of the art, more and more applications can be found, where bainite hardening generates advantages in comparison with martensitic hardening and tempering.
Bainite hardening allows higher yield strength with same hardness as tempered steel, higher tensile stresses and leads to desirable compressive stresses at the surface. However, it is necessary to carefully select the material grade according with the wall thickness or weight of the parts and the desired yield strength. Furthermore the cooling strategies have to be optimized to minimize the dwell time in the salt bath.
In the second part of the paper some practical applications and furnace designs for bainite hardening were shown. These examples give a good insight in the variety of different parts, applications and furnace designs, which can be used for bainite hardening.

REFERENCES
[1] G. Spur, Th. Stöferle (Hrgb): Handbuch der Fertigungstechnik 4/2, Wärmebehandeln, Carl Hanser Verlag (1987), S. 781 - 783
[2] Boyer, H.E.: Practical Heat Treating, American Society of Metals (1984)
[3] Dong, J. et al: Härten von Wälzlagerstählen durch verkürzte Wärmebehandlung in der unteren Bainitstufe. HTM Z. Werkst.Wärmebeh.Fertigung 60(2005)2, S. 77-85
[4] Zeitschrift Konstruktion 1/2-2012