

VACUUM-HEAT-TREATMENT OF HOT-WORK STEEL

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Abstract The heat-treatment of tool- and hot-working steels in horizontal vacuum furnaces is today's state-of-the-art technology.

Endusers like to make use of the advantages given to achieve a positive heat-treatment result by means of:

- fully automatic heat-treatment process with load thermocouple measuring during the complete cycle
- absolute reproducibility
- bright surface due to oxidation-free condition
- complete documentation of time- / temperature sequence of actual load values.

The northern american automotive industry (NADCA standard) requires within their specification for heat-treatment of hot-working steel also for quite big tools a very specific process guidance regarding heating-up and cooling down behaviour to achieve an approval for the heat-treatment furnace. For instance cooling speeds of minimum 30 °C/min from austenitising temperature down to 538 °C for a test block with dimensions of 400 × 400 × 400 mm have to be proven.

In horizontal front loaders with overpressure gas quenching facility those requirements could be obtained including the required marquenching process sequences simulation.

INTRODUCTION

The vacuum heat treatment of workpieces and components with overpressure gas quenching is today's standard. Since the introduction of vacuum

furnaces more than 20 years ago continuous developments and new concepts lead to a special technology with many advantages like:

- no decarburization
- no oxidation of components – bright surfaces
- high temperature uniformity – low distortion
- defined temperature guidance by load thermocouples – reproducible results
- documentation of load regarding the time- / temperature cycle and actual values of the load
- full automation of heat treatment process

In the vacuum furnace (Fig. 1.) today a wide range of workpieces is heat treated. Different heat treatment processes can be run. Due to this high flexibility and advantages the vacuum furnace is used very successfully by heat treatment shops and tool manufacturers as well as in the automotive, aircraft and medicine industry.

TEMPERATURE DIFFERENCE IN THE COMPONENT – REASON OF DISTORTION

On principle the cycle of each heat treatment consists of the sections heating up, holding and cooling. When heating up as well as during cooling temperature differences occur in the edges and in the core of the component. These temperature differences can not be avoided and are a reason for component stress which results into distortion. In principle this component distortion can be reduced considerably by slowly heating up and cooling. However, the microstructure, grain growth, hardenability of steel (quenching speed) and the economy demand a fast run of the processes. The new technology of modern vacuum chamber furnaces fulfils both requirements and reduces the unavoidable distortion to the demanded minimum value.

HEATING UP

Heating up in the vacuum chamber furnace is effected by convection and radiation. In the lower temperature range the fast convective heating is

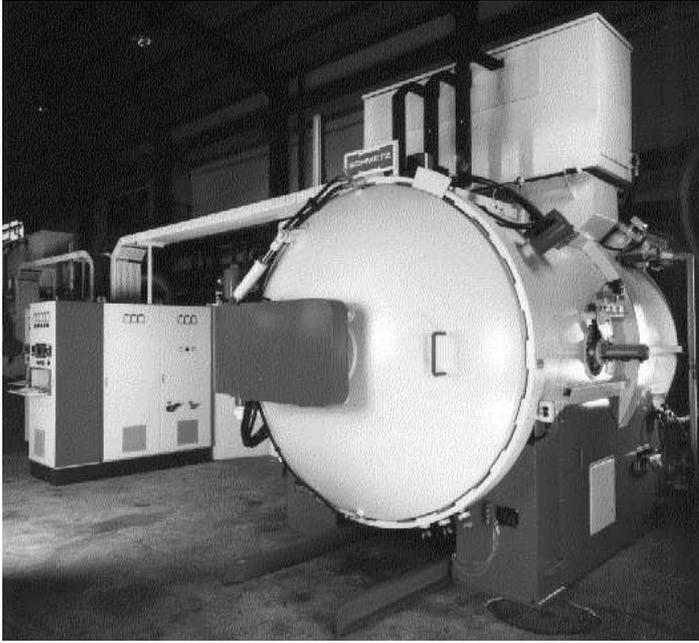


Figure 1. SCHMETZ Vacuum Furnace

made for a high temperature uniformity in the load. In the upper temperature ranges the heat transfer is dominated by radiation. One requirement for the heating is the lowest temperature difference possible within each component as well as within the whole load.

Heating up with holding steps effects a temperature compensation within each component. So the temperature differences in the edges and core of the component are reduced and a more uniform heating up of the entire load is possible. According to the form of the component, build up of the load and the advantages of a multi-zone heating is used, respectively.

HOLDING TIME

One advantage of vacuum heat treatment is the exact control of the actual temperature in the hot zone by heating thermocouples and load thermocouples within the component. The load thermocouples enable the measurement of the component temperature within the core and ensure the exact deter-

mination of the holding time. The processes run fully automatically and the documentation of heat treatment by curves of the programmer make reproducible results possible.

COOLING DOWN

The cooling process of the heat treatment must fulfil the following requirements:

- hardenability of steel
- quenching as fast as necessary and as slowly as possible
- uniform cooling of the load
- keeping the temperature difference in the component as low as possible.

The realisation of these requirements leads to the main target: fully martensitic hardness structure with lowest distortion. The quenching speed influences the strength considerably. An ideal situation would be a cooling medium with exactly that speed which reaches the sufficient hardness value. Because that would mean the lowest risk for distortion and cracks. Quenching pressure, quenching gas, cooling gas circulation speed, etc. are parameters which make it possible to select the cooling speed in steps and to achieve absolutely reproducible cycles and results. The constructive design of the furnace influences an uniform cooling decisively.

MULTI-DIRECTIONAL COOLING

The gas guidance and gas stream are important factors regarding low distortion values. From all furnace concepts the principle of through streaming with direction reversal has succeeded at the market. The company SCHMETZ introduced many years ago the principle of multi-directional cooling, system *2R* respectively the system *2x2R* (Fig. 2) The programmable cooling enables a defined, either-way vertical or horizontal cooling of the load.

The change of direction during cooling is effected according to a preselected time, for example horizontal 10 seconds from the right and 10 seconds from the left side. When cooling in a vertical direction a longer cooling time

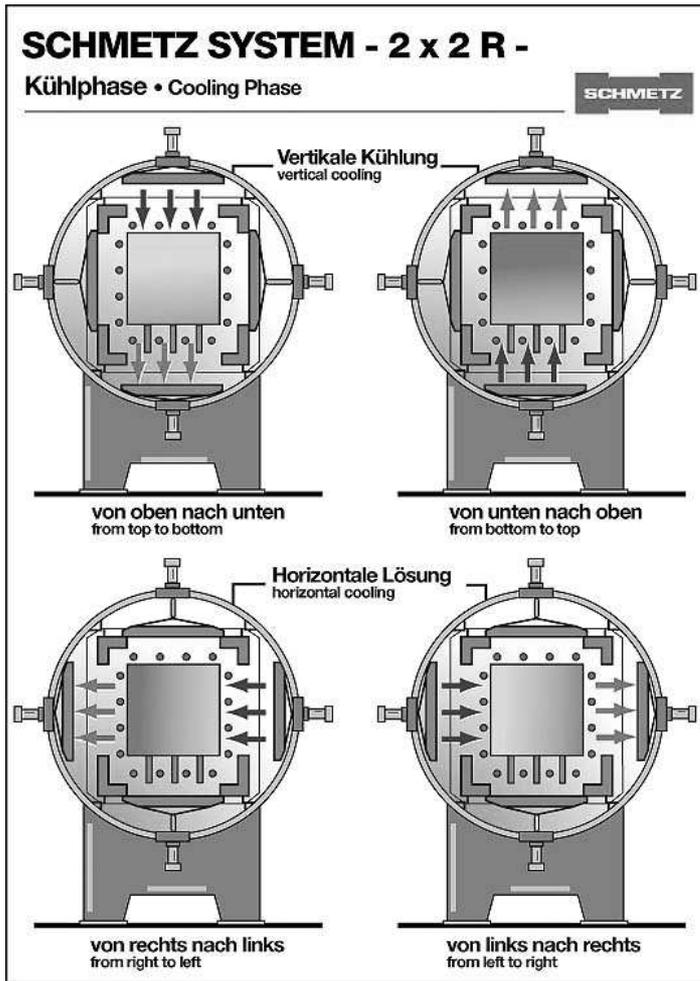


Figure 2. SCHMETZ system *2x2R*.

from the bottom, for example 15 seconds from top and 20 seconds from bottom makes sense due to the geometry of the component (conical workpieces) or the build-up of load (massive ground grid).

Also the stipulation of the cooling directional reversal can be controlled by a temperature difference control with two thermocouples. For example the

measurement of an actual temperature difference of for example 50 °C would effect the cooling directional reversal.

In addition to a low distortion heat treatment of the components this system also makes a faster and so more economic cooling possible.

MARTEMPERING

In order to minimise the thermal tension between component surface and core a "marquenching simulation" ("isothermal quenching") at a temperature higher than martensitic-start can be effected. The "marquenching simulation" lowers the distortion especially for big, geometrically complicated formed parts. For this "marquenching simulation" 2 thermocouples are fixed at one part of the load, one surface thermocouple and one core thermocouple (Fig. 3).

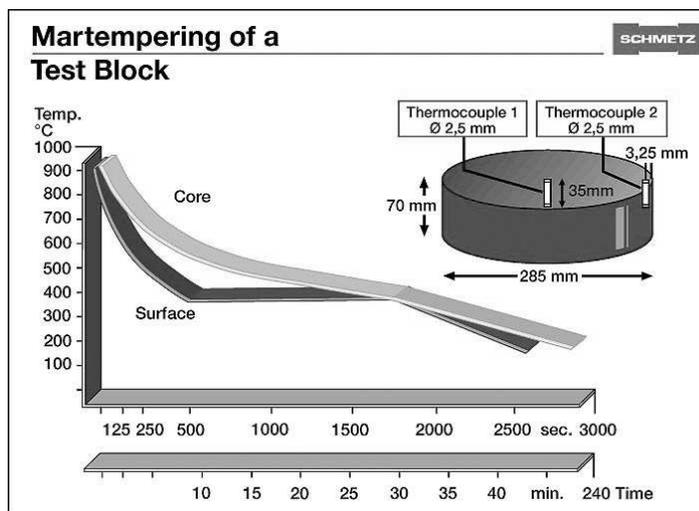


Figure 3. Martempering.

The load is cooled down from austenitizing temperature to "marquenching temperature", for example 400 °C. The surface temperature goes down to this "marquenching temperature", but the core temperature is considerably higher at this moment, for example at 650 °C. To achieve that the surface temperature is not going down on a deeper temperature, the cooling is in-

errupted and the heating is switched on. The core temperature is adapted slowly to the "marquenching / surface temperature". As soon as the surface / core adaptation has taken place the heating is switched off and the cooling down to unloading temperature can be continued.

Also at big workpiece dimensions like die casting dies the effect of heat energy within the component core is used.

VACUUM-HEAT-TREATMENT OF HOT-WORK STEEL ACCORDING TO THE STANDARD OF THE AMERICAN AUTOMOTIVE INDUSTRY

For the heat treatment of die casting dies of hot-work steel material 1.2343-H13 the American automotive industry defines in their standards (NADCA-specification) the process run for annealing. Among other requirements the minimum quenching speed is measured from austenitising temperature to 538 °C in a depth of the workpiece (T_s) of 16 mm which must be of 30 °C/min. After that a martempering process of 425 °C is demanded where the surface (T_s) must be kept between the close temperature range of 440 °C and 415 °C until the difference between surface (T_s) and core (T_c) is smaller than 90 °C. The proof must be delivered with a test component of 400 × 400 × 400 mm. At the company Edelmetallwerk Kind & Co., Germany the following heat-treatment processes in a vacuum furnace with the useful space of 1000 × 1500 × 1000 mm, payload 2500 kg, maximum quenching pressure 13 bar was realised.

QUENCHING SPEED AND MARQUENCHING AT THE SPECIMEN 400 × 400 × 400 MM

At the specimen with the dimension 400 × 400 × 400 mm, single weight 566 kg the quenching speed and the marquenching effect (Fig. 4) was checked.

The cooling rate from austenitising temperature 1000 °C to 538 °C at the depth of component of 16 mm measured in the middle of the side surface (T_s) with an overpressure gas quenching of 13 bar nitrogen was 38,9 °C/min (Fig. 5).

The demanded temperature between surface (T_s) and core (T_c) during the martempering phase could be realised (Fig. 6).



Figure 4. FORD / GMPD Specimen $400 \times 400 \times 400$ mm in furnace.

Through the fulfilment of all demanded requirements of the NADCA standard at the specimen also with a defined heating-up and tempering quality

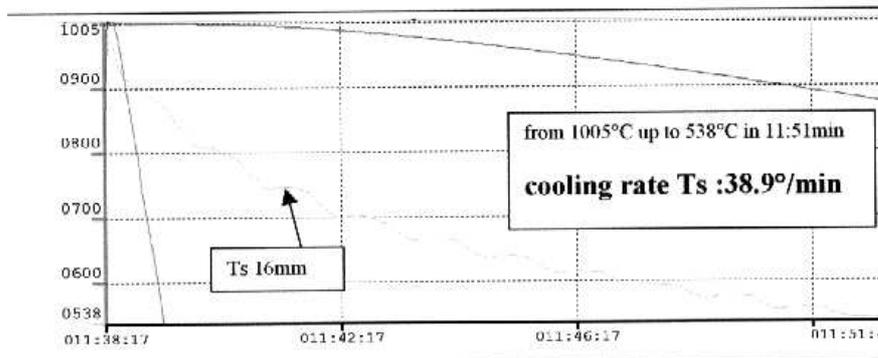


Figure 5. Cooling rate at specimen.

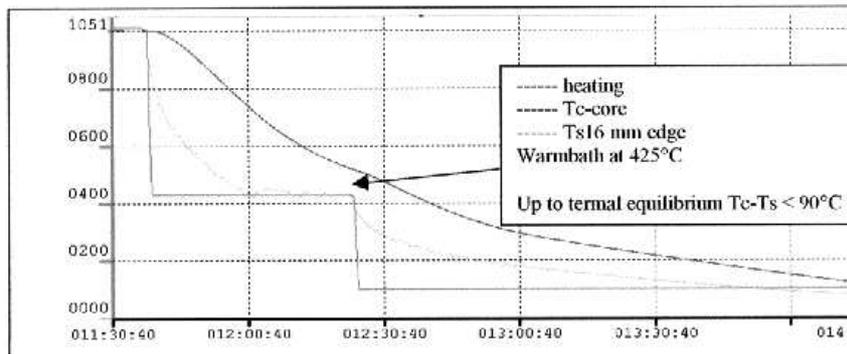


Figure 6. Marquenching phase at specimen.

the vacuum furnace with 13 bar overpressure gas quenching was released for heat-treatment of die casting dies at the company Edelstahlwerk Kind & Co.

COMPARISON OF QUENCHING SPEEDS WITH DIFFERENT WORKPIECES AND QUENCHING PRESSURES

The quenching speed between 1000 °C and 538 °C with specimen of the dimensions 100 × 100 × 100 mm, 200 × 200 × 200 mm, 300 × 300 × 300 mm and 400 × 400 × 400 mm with quenching pressures of 4,5 bar and 13 bar was measured. The temperature was again measured at a depth of 16 mm in the middle of the surface of each component. The minimum quenching speed according to the standard of 30 °C/min was even achieved with the component of 200 × 200 × 200 mm also with a lower quenching pressure of 4,5 bar (Fig. 7) with 33,36 °C/min.

So, die casting dies of hot-work steel with smaller cross sections can even be hardened with smaller quenching pressures in order to realise a heat treatment with low distortion and nevertheless an acceptable quenching speed.

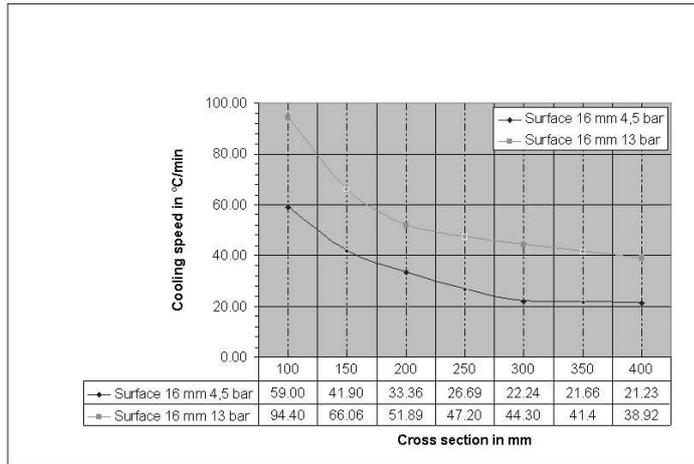


Figure 7. Comparison of cooling speed / quenching pressure for different component dimensions.

HEAT TREATMENT OF DIE CASTING DIES OF 1.2343 - H13

Die casting dies of 1.2343 - H13 automotive industry (Fig. 8) were hardened with the lowest possible quenching pressures keeping the demanded minimum quenching speeds.

The original process documentation (Fig. 9) shows the complete hardening process of a load with a net weight of 1.963 kg.

The connected extension of cooling phase (Fig. 10) shows the achieved cooling speeds for the surface (T_s) and core (T_c) with a pre-selected quenching pressure of 4,5 bar. At the surface (T_s) of these die casting dies a quenching speed of 30 °C/min was realised at a depth of 16 mm in the workpiece.

VACUUM HEAT-TREATMENT OF LOW ALLOYED MATERIALS

The conventional vacuum furnace with 10 bar overpressure has limits regarding the cooling intensity. Traditionally the demanded cooling speed of low alloyed materials is reached with oil- or salt bath processes. One of

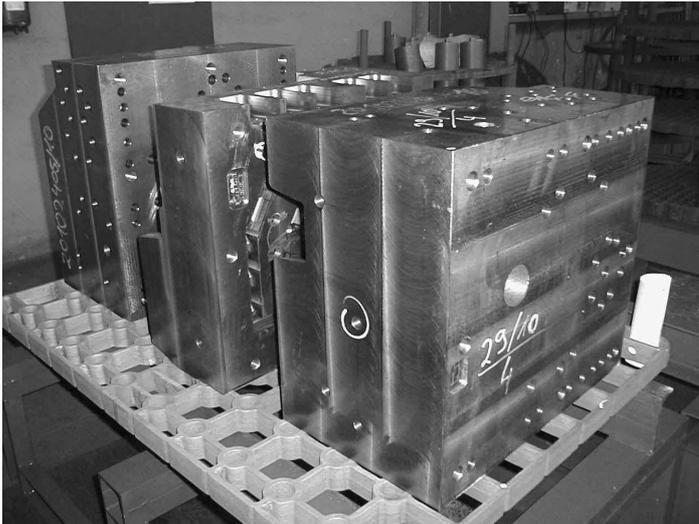


Figure 8. Example: die casting dies of 1.2343 - H13.

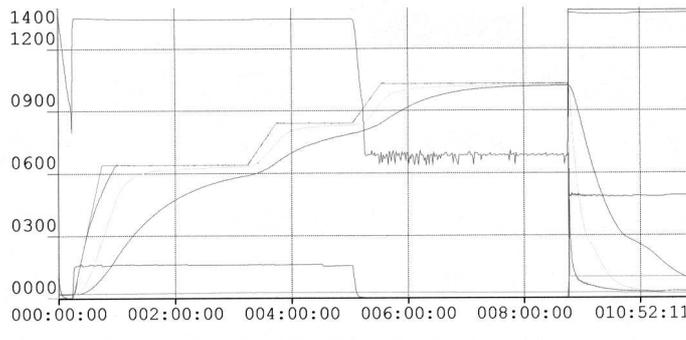


Figure 9. Programmer curve.

the many disadvantages of these techniques are the bad distortion results. Temperature differences occur during the dipping phase and also at the steam skin formation, the so called "Leidenfrostsches Phänomen".

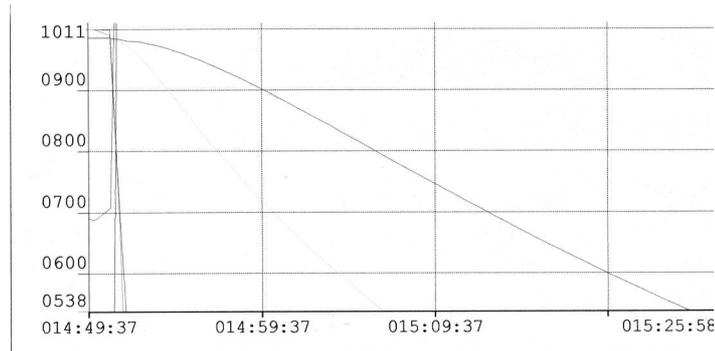


Figure 10. Programmer curve extension cooling phase.

VACUUM FURNACE WITH SEPARATE QUENCHING CHAMBER

The system *2 PLUS* (Fig. 11) offers an increase of quenching speeds in the vacuum heat treatment compared to the conventional vacuum furnace. The principle of this system is the spatial separation of the heating- and cooling process. The processes run in single chambers which are separated by a closing mechanism serving as thermal barrier. A fully automatic loading car transports the load from one chamber to the other. By separating the heating- and cooling mechanism the cooling performance could be increased considerably and at the same time the energy consumption could be lowered considerably.

With this concept the quenching speed could be doubled compared to the conventional vacuum furnace. This furnace technology is used especially for the vacuum heat-treatment of low alloyed steels like for example 1.2842-O2. In addition the operating costs and process times are lowered considerably. The SCHMETZ system *2 PLUS* is seen as an additional component to the modular furnace systems.

QUENCHING SPEED AT THE SPECIMEN 400 × 400 × 400 MM

The specimen 400 × 400 × 400 mm was tested (according to NADCA-specification) regarding the maximum achievable quenching speed in the

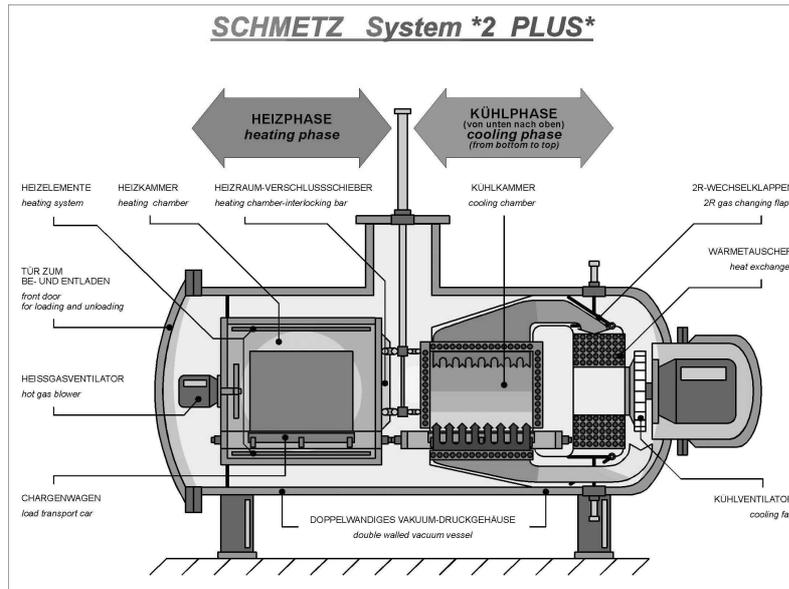


Figure 11. SCHMETZ system *2 PLUS*.

vacuum furnace with the system *2 PLUS* with the useful space of $600 \times 900 \times 600$ mm. At this process with 10 bar nitrogen overpressure quenching a maximum cooling speed from austenitising temperature to 538°C of $62^\circ\text{C}/\text{min}$ in the surface (at a depth of 16 mm) was achieved.

SUMMARY

The modern furnace technology enables to do a low distortion vacuum heat treatment of several components and steels.

Bigger components can be annealed with low distortion and a high profitability.

The advantages of new developments in vacuum heat-treatment with overpressure gas quenching can also be transferred to lower alloyed steels.

