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STUDY OF VACUUM HARDENING MACHINE

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ABSTRACT

Heat-treatment of tools, workpieces and metal components had been carried out over decades to get desired hardness of workpieces. Heat-treatment of tool steels is very important process in getting the optimal hardness of tools which is required for their efficient functioning. Use of conventional heat treatment process like carburizing, annealing, normalizing, stress relieving, tempering, flame hardening, induction hardening; case hardening etc. are the most widely used methods for heat treating. The heat-treatment of tool- and hot-working steels in horizontal vacuum furnaces is today's state-of-the-art technology. In the vacuum furnace today a wide range of workpieces are heat treated. 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.

Almost all of the common heat-treatment processes like annealing, hardening, brazing, annealing, stress relieving and tempering etc. can be performed quickly and easily. As there is a total separation of the furnace working area from the environment, it permits precise and effective heat treatment processes to be carried out irrespective of outer environmental conditions.

Keywords: Vacuum Hardening, Packing Of Component, Quenching, Multi-Direction Cooling, Martempering

I. INTRODUCTION

Use of conventional heat treatment processes for hardening of workpieces and components had been widely used over the decades. 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 over the conventional methods of heat treatment.

As the conventional heat treatment processes were performed in open environment; problems like oxidation, decarburization, distortion, etc. were very common drawbacks of any process, accurate temperature control and holding time is not possible and completely based on trial and error method. With the introduction of vacuum hardening machine, these drawbacks are overcome since the heat treatment processes are carried out in closed chamber under vacuum. As there is no atmospheric air under vacuum, complete oxidation of work pieces is prevented and also it is possible to control the holding time and temperatures of vacuum furnaces by making use of thermocouple at different parts of work piece.

Heat treatment processes performed by conventional methods releases too much of harmful gases which causes threat to human beings as well as to nature. Vacuum furnaces are proving a boon to nature since it is an isolated from environment. Thus vacuum furnaces are considered to be an eco-friendly affair.

II. REASONS OF DISTORTION

Prime reasons for distortion in the component by making use of conventional hardening process is temperature difference over the surface area of the component and improper holding time for various components.

2.1 Temperature Difference in the Component

Every heat treatment process consists of the sections heating up, holding and cooling. When the component is heated up as well as cooled, temperature differences occur in the edges and in the core of the component. These temperature differences cannot 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 [1].

2.2 Improper Holding Time

In conventional hardening processes exact control of holding time is not possible. It varies depending upon the size and shape of the component. It is usually based on trial and error method and the experience of the operator. Thus exact control of time parameters is a difficult task .Due to improper holding time. The component may get distorted because of uneven heating of its surface, especially in case of bigger unsymmetrical components, the problem is more severe. So, these drawbacks can be easily overcome by making use of vacuum hardening machines [1].

2.3 Vacuum Hardening Machine

The Fig.2.1. shows vacuum hardening furnace which is being used progresively for various heat treatment processes of component for mass production. The introduction of vacuum furnace since 20 years ago had enabled us 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 without compromising the mechanical properties of the components [1].

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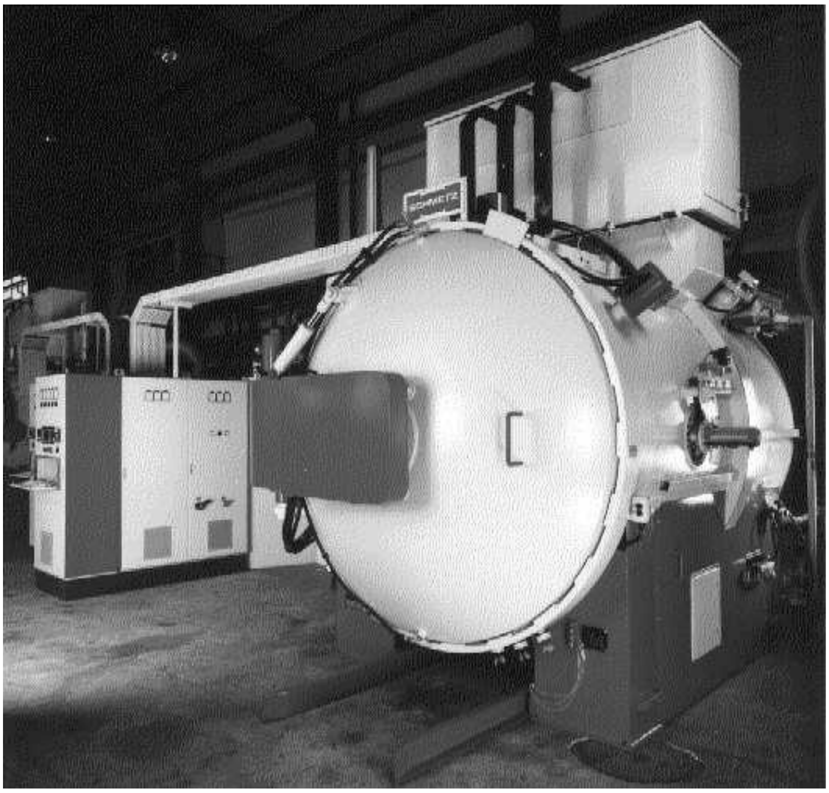

Fig.2.1. Vacuum hardening machine.

(Vacuum furnace)

The significance of vacuum furnaces in heat treatment has been increasing continuously and the area of tool steels has been of key importance for a few decades .This is due to the neutrality of vacuum as a protective atmosphere and the ideal surface quality obtained in the course of heat treatment. Therefore, the most important applications for vacuum technology are in the aviation and aerospace industries, in jet engine assembly, nuclear technology, medical technology or automotive engineering [5].

III. HARDENING PRINCIPLES

3.1 Heating of Component

Heating up in the vacuum chamber furnace is carried out by convection and radiation. In the lower temperature range the fast convective heating is 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 [1].

Heating up with holding steps effects the 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. The time required for heating depends on the component to be hardened [1].

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3.2 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 determination of the holding time. The processes run fully automatically and the documentation of heat treatment by curves of the programmer makes reproducible results possible [1].

3.3 Cooling down of component

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 [1].

IV. HARDENING PROCEDURE IN VACUUM FURNACE

4.1 Packing of Components in Fixtures

Equally important process parameters are heating uniformity and temperature uniformity within the working area (±5^{o}C) which are crucial for the accuracy of austenitizing temperature for the entire workload and each work piece alone and which facilitate short holding times. It is not only the furnace properties that influence the above parameters but largely the experience in arranging individual elements of the workload as shown in Fig.4.1.1. A failure to meet the temperature condition may result in a failure to reach the austenitizing temperature or overheating, which will adversely influence quench outcomes and steel microstructure (grain growth, release of carbides) [2].

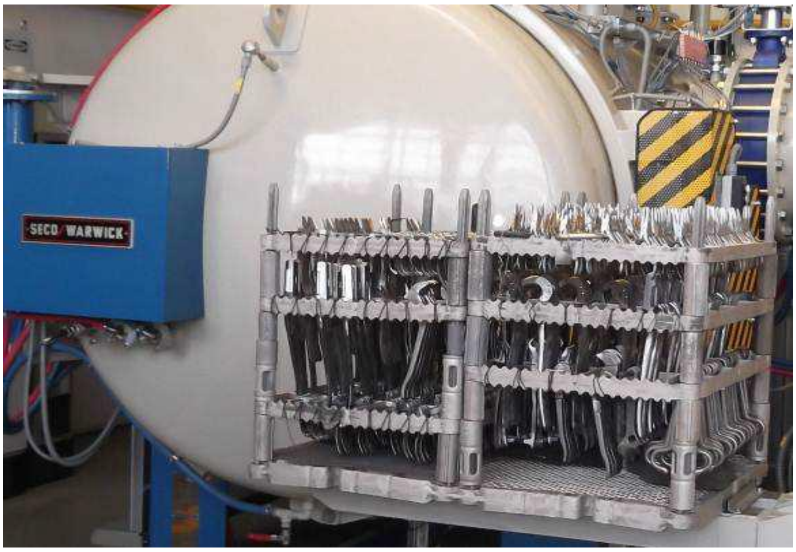


Fig.4.1.1. Packing of surgical tools in workload.

4.2 Loading into the Vacuum Chamber

After packing, loading of component into the chamber is done by making use of forklift. Proper loading of component is important for effective hardening to take place. Skilled operators are required for loading purpose. Loading of surgical tools is shown in Fig.4.2.1. [2].

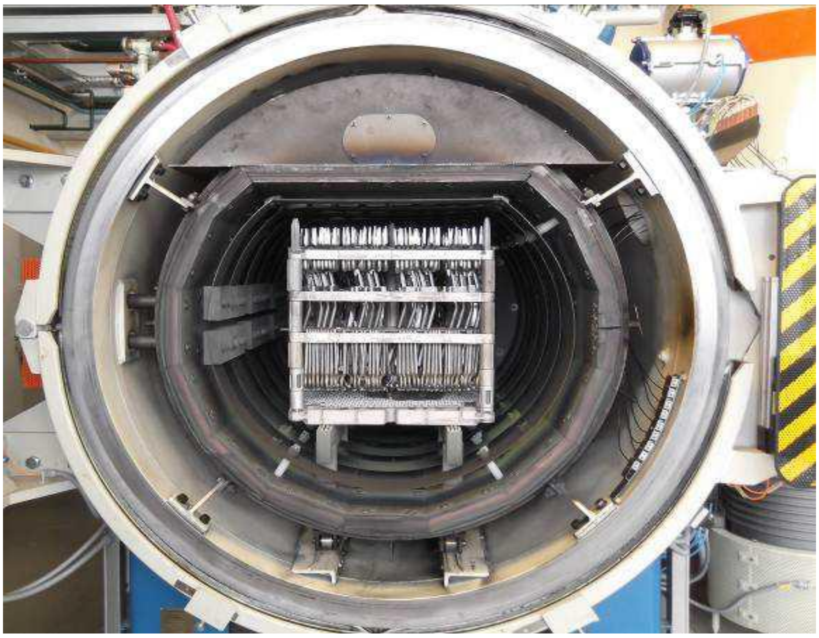


Fig.4.2.1. Workload of surgical tools into the chamber.

4.3 Evacuating the Chamber

After loading the load into the furnace the first process step in the vacuum heat treatment is the evacuation of the furnace vessel. For this, usually a multilevel mechanical vacuum pump station is installed. By means of the continuously variable speed control of the roots pump with a frequency converter the required vacuum value within the furnace can be controlled whereas at a non-controlled pump it always runs with maximum speed. At all vacuum furnaces the evacuation time is reduced due to the extreme compact structure of the furnace vessel as less furnace vessel volume has to be evacuated [3].

4.4 Heating and Soaking of Components

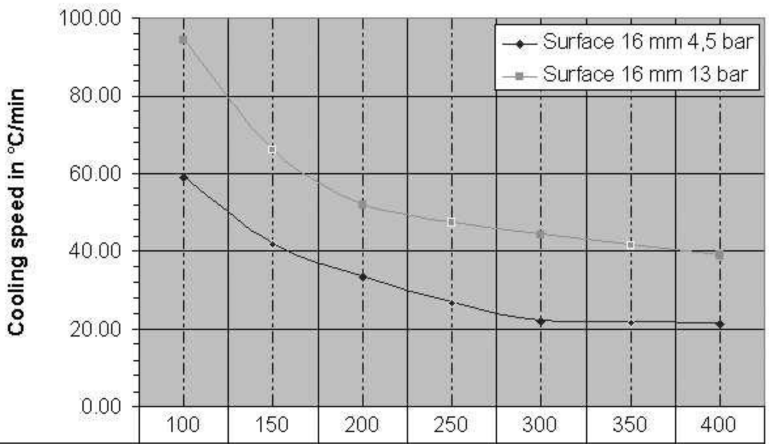
The bigger the mass in the hot zone and load, the more energy has to be supplied for the warm up. The aim is of course to treat as much parts as possible within the cycles. Thus the mass reduction has to be limited to the loading media. Thus all parts of the heating are optimized regarding their function and weight. The heating rods and heating bridges have the minimum possible weight without any risks regarding their stability and lifetime. Generally Graphite or Molybdenum rods are used as heating elements [3].

During heating of the components, convective heating takes place up to 950°C.After 950°C heating is done mainly by radiation effect which is more dominant than convective forces at higher temperature. The time required for heating ranges from 3 to 5 hours followed by soaking time of 2 to 4 hours depending upon the thickness of component to be hardened [4].

During the heating and temperature soaking cycles the supplied electric heat energy has to balance "empty losses". These "empty losses" of the hot zone are reduced by means of an insulation structure that is designed as tight as possible. By means of the additional use of a reinforced insulation there are even better insulation results. By means of a possible modification of vacuum furnaces there is also a high energy saving potential at many older furnaces [3].

4.5 Cooling of Components (Quenching)

The cooling gas pressure which is to be pre-selected is determined by the cooling gradient that is necessary. Here; not only the cooling gas speed is decisive but rather the volume stream of the gas and the uniform gas distribution throughout the load's useful space. In order to guarantee a most uniform and thus low-distortion gas quenching the gas stream is lead into the complete useful space of the furnace via special gas guiding devices [3]. The high cooling speeds necessary for the hardening process are achieved by the gas pressure and a high gas volume stream. For this purpose the use of a high-capacity electrical motor for the cooling gas fan is necessary. Generally liquid nitrogen is used as a coolant. The graph 4.5.1 shows the cooling speed relative to the cross section area of component [3].



	100	150	200	250	300	350	400
Surface 16 mm 4,5 bar	59.00	41.90	33.36	26.69	22.24	21.66	21.23
Surface 16 mm 13 bar	94.40	66.06	51.89	47.20	44.30	41.4	38.92

Graph 4.5.1.Comparison of cooling speed /quenching pressure for different components.

4.5.1 Vacuum Furnace with Separate Quenching Chamber

The modern vacuum furnace has improved over a period of time and it comes with separate quenching chamber as shown in Fig.4.5.A.1. The system offers an increase of quenching speeds in the vacuum heat treatment processes as compared to the conventional vacuum furnace [1].

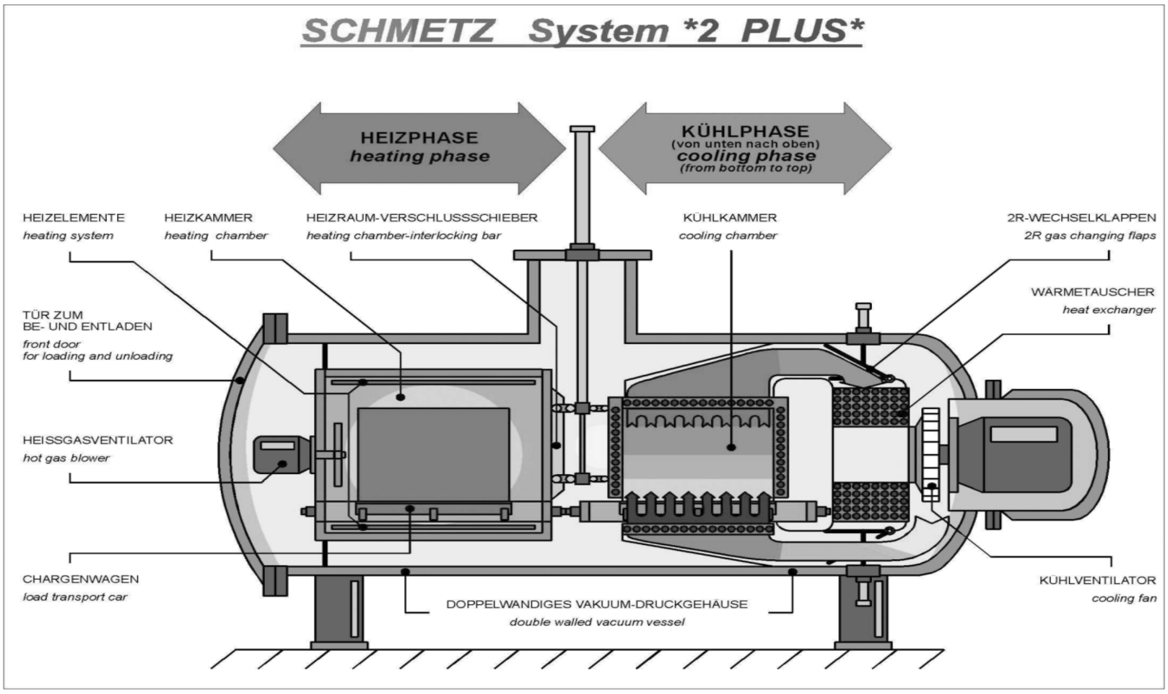


Fig.4.5.A.1. Cross-section of schmetz vacuum furnace.

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 [1].

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. In addition the operating costs and process times are lowered considerably [1].

4.5.2 Multi-Direction Cooling

The Fig.4.5.B.1 shows cooling directions inside the vacuum chamber. The change in direction takes place according to preselected value. While cooling in vertical direction, a longer cooling time is required as compared to horizontal [1].

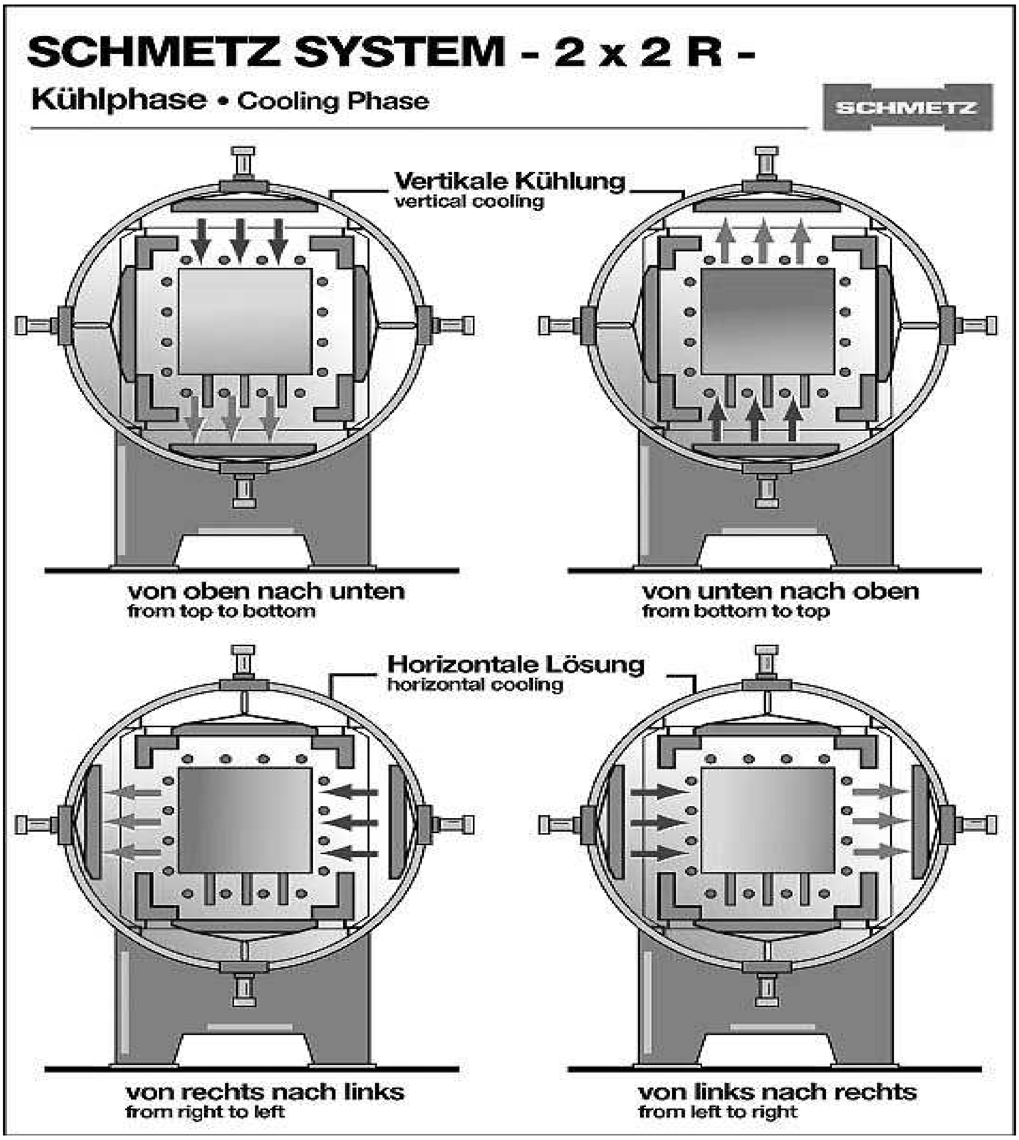
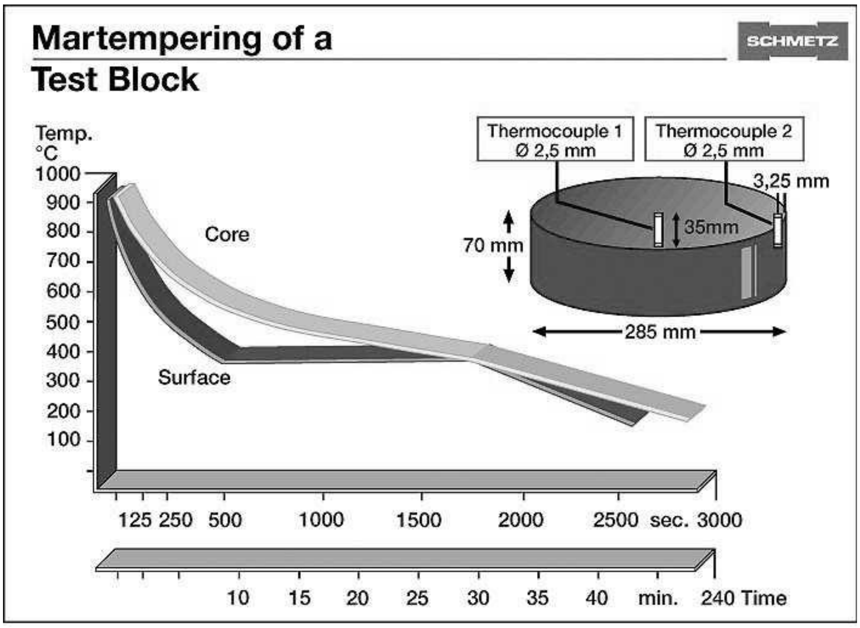


Fig.4.5.B.1. Multi-direction cooling

4.6 Martempering

In order to minimise the thermal stresses between the component, surface and core "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 [1].



Graph 4.6.1.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 interrupted and the heating is switched on. The core temperature is adapted slowly to the "marquenching / surface temperature" as shown in Graph 4.6.1.. 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 [1].

V. MERITS OF VACUUM FURNACE

- No oxidation of components.
- Low distortion of larger components.
- No decarburization.
- High temperature uniformity.
- Thorough hardening of components.
- Full automation of heat treatment process.
- Ecofriendly device.

VI. DEMERITS OF VACUUM FURNACE

- Initial cost of setup is high.
- Skilled operators are required for operating the machine with Knowledge of computer software.

VII. APPLICATIONS

- Hardening of coining dies and punches.
- Hardening of hot forging dies.
- Toughening of high speed tool steels like taps, milling cutters, tool grips, etc.
- Hardening of Surgical instruments.
- Hardening of tools for extrusion and pressing, e.g. those used in foodstuff industry, animal feed industry, and the like.

VIII. CONCLUSION

The changing use of materials and the global competition from developing countries have made traditional heat treatment processes relatively uncompetitive. Nevertheless, the business that anticipate the needs of market by capitalizing on user education, process design and minimizing costs by efficient processing are the ones gaining profit. Thus by making use of vacuum furnaces we can get high quality products with minimum defects at reasonable prices. As there is separation of heating chamber from the environment, it does not cause any harmful effect to environment as in case of conventional hardening processes. Thus it is an ecofriendly affair with huge future scope.

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