ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 11
Special Issue
3/2011

163 – 170

30/3

# Cast construction elements for heat treatment furnaces

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Received 09.06.2011; accepted in revised form 27.07.2011

## Abstract

The study presents sketches and photos of the cast creep-resistant components used in various types of heat treatment furnaces. The shape of the elements results from the type of the operation carried out in the furnace, while dimensions are adjusted to the size of the furnace working chamber. The castings are mainly made from the high-alloyed, austenitic chromium-nickel or nickel-chromium steel, selecting the grade in accordance with the furnace operating conditions described by the rated temperature, the type and parameters of the applied operating atmosphere, and the charge weight. Typical examples in this family of construction elements are: crucibles, roller tracks, radiant tubes and guides. The majority of castings are produced in sand moulds.

**Keywords**: Innovative foundry technologies and materials, Castings for heat treatment plants

## 1. Introduction

The heat- and creep-resistant metal parts forming accessories of the heat treatment furnaces include [1÷3]:

1. Functional accessories (e.g. pallets or baskets) on or in which the heat treated parts are placed. The task of this equipment is to ensure similar heat treatment conditions to all parts and to make their loading into and unloading from the furnace easier. The operating conditions of the equipment result from the heat treatment regime applied to the charge, which in practice comes down to:
   – cyclic heating and cooling, and
   – periodic effect of the furnace atmosphere.
2. Construction elements that allow the heat treatment to be carried out in the furnace. These elements are usually permanently fixed in the furnace. Depending on function they are supposed to perform in the furnace, the conditions under which they operate are:
   – relatively stable when these elements are subjected to a continuous influence of the furnace atmosphere only, with rather insignificant changes in temperature (e.g. radiant tubes, crucibles, or rotors), or
   – variable, when the elements are subjected to complex thermo-mechanical loads arising from direct contact with the charge (e.g. bottom plates, roller tracks and guides), combined with simultaneous constant effect of the furnace atmosphere.

The majority of creep-resistant metal parts are cast in sand moulds as monolithic elements or parts of larger assemblies [2].

Castings operating in furnaces in which the rated temperature does not exceed the value of 1000°C are made from high-alloyed steels (Cr, Cr-Ni and Ni-Cr type). The selection of alloy chemical composition is also determined by the type and parameters of the furnace atmosphere and by the thermo-mechanical loads to which the castings will be subjected during operation. In the case of high-temperature furnaces, which nevertheless operate at a temperature below 1250°C, castings made from nickel or cobalt alloys are also used [1÷4].

The cast functional accessories were presented in [3]. This article discusses the most commonly used cast construction elements for heat treatment furnaces.

## 2. Cast construction elements

In the majority of heat treatment furnaces, regardless of their manufacturer, the shape of construction elements that perform the same or similar tasks is similar. Using this similarity, a classification of this family of castings based on the most important tasks they perform has been proposed:

1. Air-tight separation of the furnace working chamber and/or heating elements or exhaust gas from the rest of the furnace installation operating at high temperatures – **insulating elements**.
2. Charge transfer inside the furnace - **elements of the internal charge handling system**.
3. Protection of ceramic furnace lining from damage during charge loading and unloading - **shielding elements**.
4. Temperature field equalisation and/or forcing a uniform flow of atmosphere in the working chamber - **rotating elements** (fans).

### 2.1. Insulating elements

Typical products included in this group of elements making furnace equipment are designed to perform the following tasks:

– provide an air-tight working chamber in the furnace (crucibles, muffles, and retorts), and
– protect heating elements from the effect of furnace atmosphere (one- and multi-segment radiant tubes).

Crucibles, muffles, and retorts of small size (Fig. 1) and weight (up to about 100 kg) are produced by casting. Elements larger are shaped from the steel sheet. Radiant tubes are usually cast.

Metal crucibles operate in bath furnaces heated by electricity or gas (max. operating temperature 1000°C). They are filled with molten salt or liquid metal (usually lead). Crucibles are cylindrical (Fig. 1), rectangular or formed like a polygon cube. In cast version, their capacity is up to 200 litres. Castings are characterised by uniform wall thickness on the entire cross-section and a collar formed in the top part (Fig. 1), used for fixing the crucible in the furnace housing/ lining.

The crucibles, whose operating temperature does not exceed 500°C, can be made from carbon steel or corrosion-resistant steel. At higher temperatures, the recommended alloys are GX40CrSi24 or GX40CrNiSi25-20 cast steel (PN-EN 10295: 2002).

Muffles and retorts in the heat treatment furnaces perform simultaneously several functions:

– prevent contact between the gaseous atmosphere kept in their interior and the surrounding atmospheric air,
– facilitate the circulation of working atmosphere, and
– provide uniform temperature distribution in the working chamber.

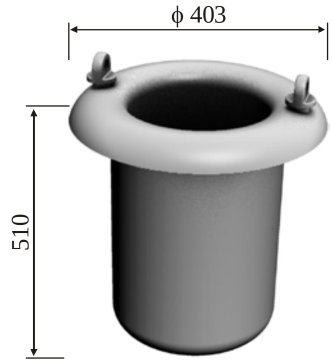


Fig. 1. Crucible operating in a PET-22/45 salt bath furnace with lugs fastened by screws for easy transport [5]. Wall thickness 25 mm, material: GX40CrSi24 or GX40CrNiSi27-4, according to the drawing provided by ELTERMA (present SECO/WARWICK ThermAL SA)

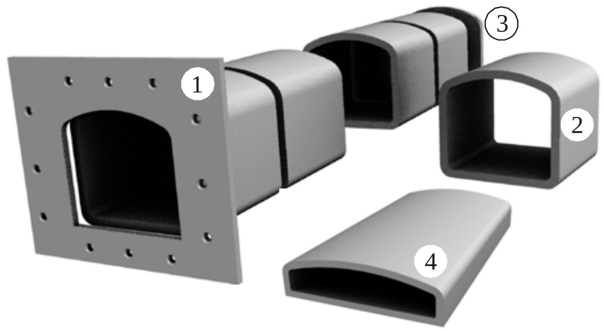


Fig. 2. Box-shaped muffle [5]; see the text for explanation of symbols used in the drawing

Muffles consist of one or more segments (Fig. 2). By welding the successive segments, muffles of a length reaching even several metres are made. In continuous furnaces, muffles are usually closed with plates on both sides (Fig. 2-1); the plates help in fixing the muffle to the furnace lining. In batch furnaces, one side is closed with a welded plate (Figs. 2-3). The walls of a muffle are often designed as folded elements to enlarge the heat transfer surface area and compensate for dimensional changes resulting from changes in the operating temperature.

In the case of furnaces designed for lot or mass heat treatment, the working cross-section of a muffle is adapted to the shape of the heat treated part (see Figs. 2-2 and 2-4). Metal muffles are used in low- and medium-temperature furnaces, and therefore, similar to crucibles, they are produced from various grades of the carbon cast steels and low- and high-alloyed cast steels.

An example of the muffle of a different design is muffle operating in a drum furnace (Fig. 3). The muffle-drum of a circular section or section in the form of polygon cube is the design used for heat treatment of small parts, like screws for steel plate, nuts or bolts.

Drum furnaces are designed for continuous (Fig. 3) or periodic operation. The difference in the design of muffles for these furnaces mainly consists in the presence of a discharge door (Figs. 3-3).

Cast muffles are designed as one monolithic item (Fig. 3), or they are made in segments. The drum has a diameter of 400 to 600 mm and is from 1500 to 3000 mm long [6, 7]. In furnaces for continuous operation, the drum rotations make the charge move along a helically-shaped baffle from the charging to the discharging door (Fig. 3-2).

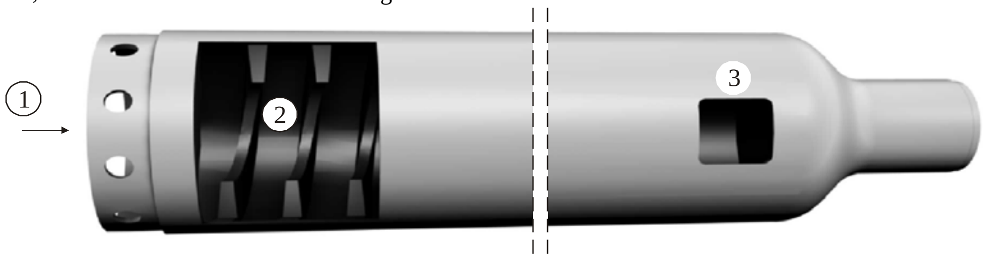


Fig. 3. Cast monolithic muffle for continuous drum furnace [5]: 1 - loading of charge, 2 - internal helical baffle, 3 - discharge door, material: GX40CrNiSi25-20, GX40NiCrSi35-17 or GX40NiCrSiNb38-19

Retorts are cylindrical in shape and have uniform thickness (about 5-20 mm) on the entire cross-section. They are used in the furnaces of:

– pit-type heat treatment installations (Fig. 4-1) (operating temperature 700-1000°C), and
– endothermic/exothermic-endothermic generators (operating temperature 700-1000°C), and
– ammonia dissociators (operating temperature 1000-1200°C).

Retorts are heated electrically or by gas.

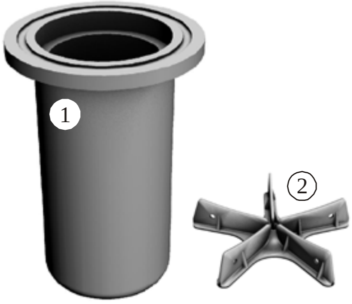


Fig. 4. Pit furnace retort (1) and base for its installation at the bottom of the furnace chamber (2) [5]; material: GX40CrNiSi25-20, GX40NiCrSi35-17 or GX40NiCrSiNb38-19 or steel of similar chemical composition

Retorts in pit furnaces are designed in a large variety of sizes from the dimensions of the working space $\phi$270×400 mm to $\phi$1200×2600 mm [6, 7] and larger. The retort is either supported by a collar or can rest on a cast base placed on the bottom of the furnace (Fig. 4-2).

By the technology of casting, only the smallest retorts are made. Using welded steel sheet, the wall thickness is 2-3 times thinner, which has a positive effect, reducing the energy consumption level and total weight of the retort. In spite of these facts, it was found that cast retorts are more durable than retorts made from rolled tubes. As regards cast retorts, those made by gravity technique have life shorter than the retorts centrifugally cast [6, 7].

The retorts operating in generator furnaces are made from 120 to 400 mm tubes rolled or cast [6]. The bottom of the retort is closed with a cast canopy of properly selected diameter (Fig. 5). As with the retorts operating in pit furnaces, the retorts are more durable when they are cast [6, 7].

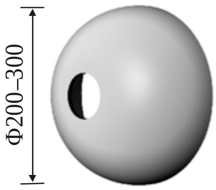


Fig. 5. Canopies with walls from 12 to 20 mm thick used in the generators manufactured by SECO/WARWICK ThermAL SA [5]; material: G-NiCr28W

In many design embodiments of the furnaces, radiant tube heaters are used (Fig. 6). Straight radiant tubes (Fig. 6a) can operate in horizontal or vertical position. Multi-segment structures (Fig. 6b-c) are mounted in a horizontal position. The straight section of pipe with a length of up to several metres and a diameter of about 160 mm may consist of more than one segment. The construction of radiators is completed with the following accessories:

– elements enabling fixing the radiator to the furnace body (Fig. 6a-1),
– supports to prevent distortion (hanging down) of tubes during operation (Figs. 6-2 and 7-2),
– elements closing the space inside the tube (Fig. 6-3),
– elbows connecting the straight tube sections (Figs. 6-4 and 7-4).

Another example of elbows/ bends connecting radiant tubes is a TermIn type connector (Fig. 8) of low-voltage heating elements developed by SECO/WARWICK from Świebodzin.

The operating temperature of the tube surface (heated electrically or by gas) is 900-1150$^{o}$C. The life of tubes increases when rolled tubes are replaced by tubes gravity cast. Further life increase is obtained by application of the centrifugally cast tubes [1, 2, 6].

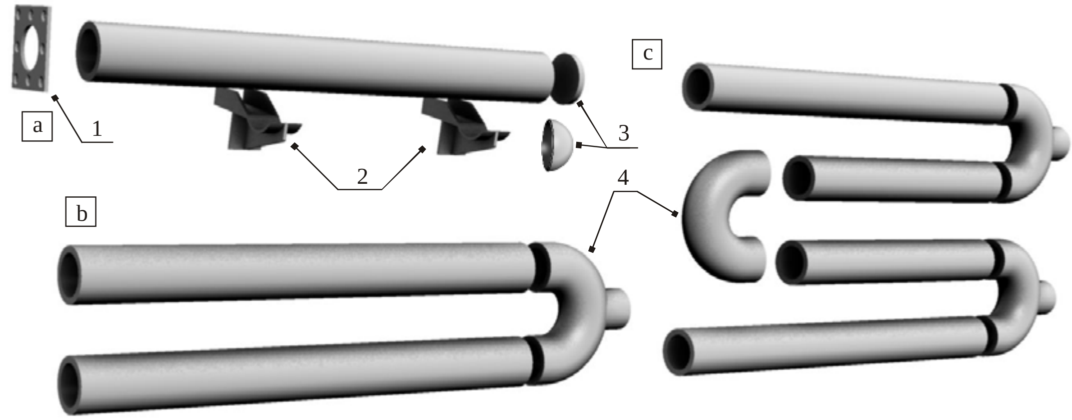


Fig. 6. Radiant tubes: a) single-segment type, b and c) two and four-segment type [5]: 1 - element used to attach the tube to the housing of the working chamber, 2 – tube support, 3 – element closing the tube, 4 - elbows linking individual tube members; material: GX40NiCrSi35-17 or GX40NiCrSiNb38-19

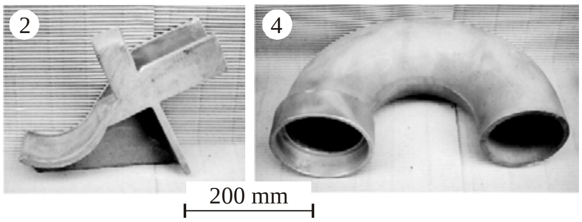


Fig. 7. Cast radiant tube support (2) and tube-connecting elbow (4) (designation of components as in Fig. 6) [5]; material: GX40NiCrSiNb35-17

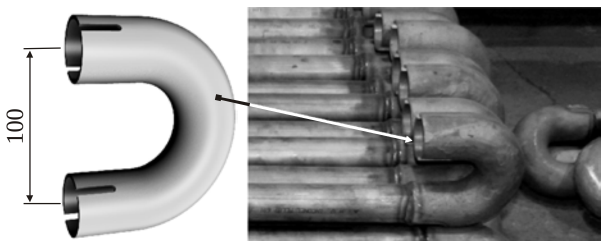


Fig. 8. Connector of heating elements used by SECO/WARWICK ThermAL SA [5]; material: GX50NiCrCoW35-25-15-5

## 2.2. Elements of the internal charge handling system

Roller tracks are the oldest and most widely used design solution enabling smooth travelling of charge inside the furnace chamber (Fig. 9).

A roller track consists of two sections (Fig. 9a) mounted on the furnace bottom, symmetrically along its longitudinal axis. Each section can consist of several segments (Fig. 9b), depending on the length of furnace chamber.

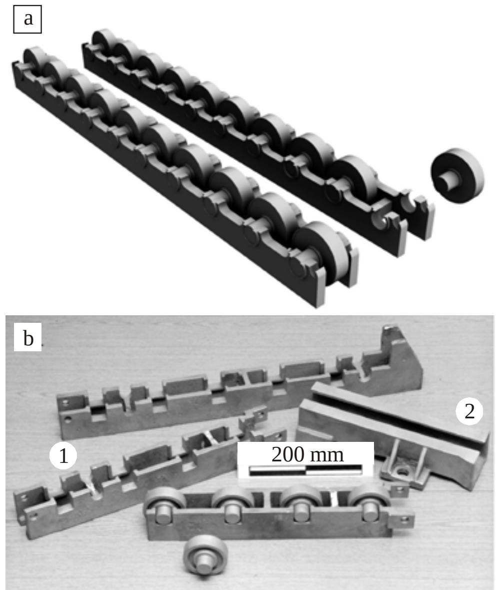


Fig. 9. Roller tracks [5]: a) a draft scheme according to IMP Company folder, b) for operation in PeKat 1 or 2 type furnaces made by SECO/WARWICK ThermAL SA: 1 – track members, 2 - chain guide mounted between the tracks; material: GX40NiCrSiNb35-18

Besides multi-roller members, also single-roller members are used (Fig. 10); in an appropriate number they are mounted in two rows on the furnace bogie, symmetrically along its longitudinal axis. Rollers of this type are used in muffle furnaces in which the charge is handled by:

– shaker plates /chutes (Fig. 11), or
– wire woven belts.

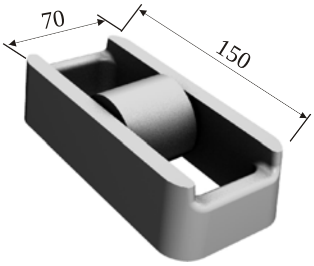


Fig. 10. Roller moving in a clamping ring [5]

The shaker plate (Fig. 11) resting on rollers performs reciprocating movements. Adjusting properly the plate "back and forth" feed rate, the heat treated parts travel successively throughout the entire length of the furnace chamber. The shake-generating system allows the shake frequency to be very flexibly adjusted to the object's shape [6, 7].

A typical plate is characterised by:

- corrugated surface to facilitate even charge distribution and movement (Fig. 11), and
- multi-segment welded structure of a total length typically exceeding a few metres.

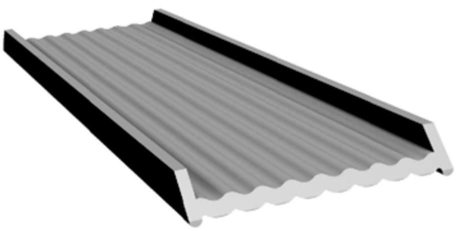

Fig. 11. Shaker plate operating in a muffle furnace [5]

Conveyor plates and belts working in muffle furnaces are used in the heat treatment of small and fine parts, e.g. screws or engine valves [6].

Generally, for the handling equipment operating in medium- and high-temperature furnaces (operating temperature of 700-1050$^{o}$C), two types of metal belts are used:

- woven from Cr-Ni or Ni-Cr steel wire [6, 7], or
- composed of the cast segments (Fig. 12a).

Cast segments are of similar shapes; the construction of those that form the belt edge is additionally provided with a safety side board protecting the heat-treated parts from falling out (Fig. 12c). The belt is driven by a drum (Fig. 12b) mounted on the discharge side of the furnace. The conveyor length can reach 30 metres, while its width is between 300 to 2000 mm [6, 7].

Structurally less complex, compared to the belt conveyors, designs of the in-furnace charge handling system are shown in Fig. 13:

a) a guide and push rod system operating in a versatile chamber furnace with quenching bath, and
b) walking hearth operating in a chamber furnace.

A guide (Fig. 13-1) and a mating push rod (Fig. 13-2) are mounted on the bottom of the carburising furnace between the ceramic sliding rails, which bear the tray and/or basket with the heat-treated items. When the part of the heat treatment process which is carried out in the furnace chamber is completed, the rod pushes the tray and/or basket from the chamber to the quenching vestibule and returns next to the starting position. The operating temperature of the heat-treated items does not exceed 1050$^{o}$C.

The walking hearth (Fig. 13b) operates in a heating furnace in the atmosphere of air at a temperature of about 1000°C. The charge is moving stepwise in the furnace chamber along the furnace hearth from the charging to the discharging side. The chamber hearth consists of four rows of supports: two permanently fixed and two movable. The supports are moving along a trajectory forming a closed circuit, which means that they raise the whole batch of items and move it forward by a distance equal to the pitch (“notch”) on castings; they lower the batch (below the level of the fixed supports), let it rest on these supports and move back. An example of the task that furnace of this type performs is heating to a predetermined temperature the steel rods before they are rolled up in springs.

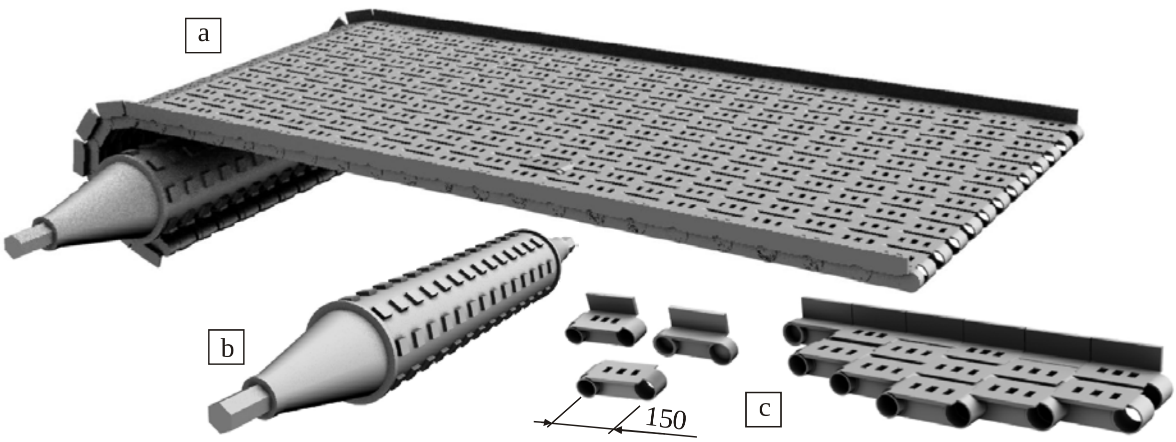


Fig. 12. Belt conveyor composed of cast segments [5]; a schematic representation according to a folder published by COURTH Company - designations are explained in the text; material: GX40NiCrSi35-17 or GX40NiCrSiNb38-19

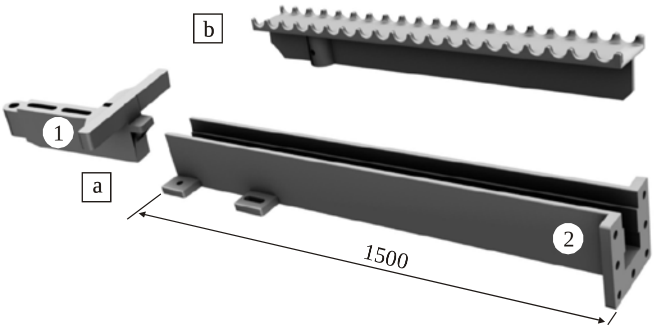


Fig. 13. Sketches of cast accessories for transport of charge in the furnace chamber designed and made by SECO/WARWICK from Świebodzin [5]: a) trays and/or baskets pulled out from the chamber; material: GX40CrNiSi25-20, b) heat-treated steel rods travelling stepwise in the chamber; material: GX40CrNiSi25-20

Guides and walking tracks are cast as monolithic items, or in the case of furnaces with very long working chambers, they consist of two or more segments.

The examples of cast parts facilitating the transport of charge do not cover all designs used in the furnaces for heat treatment. Other widely used systems are rollers for the transport of:

- tubes and rods (Fig. 14a, b),
- metal sheets or plates (Fig. 15), or

different types of truck wheels (Fig. 16).

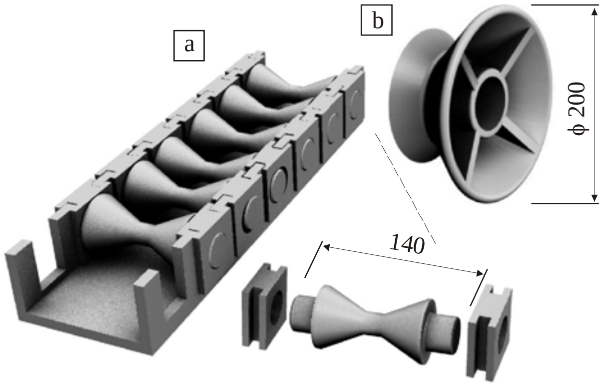


Fig. 14. Sketches of transport rollers mounted individually or in assemblies [5]: a) according to a folder of FAI-FTC Company, b) according to a drawing supplied by SECO/WARWICK from Świebodzin; material: GX40CrNiSi18-9

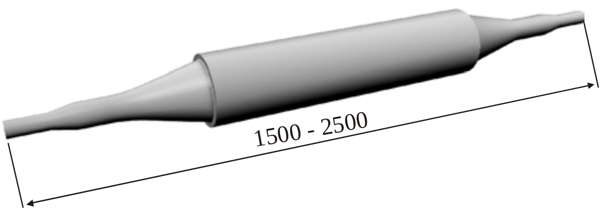


Fig. 15. Sketch of a roller to facilitate transport of sheets /plates in the chamber of a batch furnace according to a folder supplied by POSE-Marre Company [5]

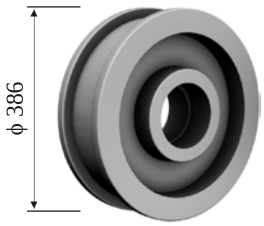


Fig. 16. Sketch of a wheel for transport truck designed by SECO/WARWICK SA from Świebodzin [5]; material: GX40CrSi13

## 2.3. Shielding elements

Some elements of the furnace interior accessories require shielding but with no additional requirement for the shield to be air-tight, as in the case of elements discussed under section 2.1. If this is the case, then the main task of the shield is to protect the enclosed element from mechanical damage.

The first two examples of such solutions are shown in Figs. 17 and 18. When the furnace bogie hearth is equipped with an electric heating system (Fig. 18) placed on a ceramic substrate, the task of the shield is not only to keep the heavy charge in stable position above the heating elements, but also to slightly reduce the heat flow in this area. To satisfy these requirements, a shield composed of 12 openwork pallets and 54 racks was designed (Fig. 18b-d). When the hearth is not heated, the task of the shield is to protect from damage the ceramic lining, especially during loading and unloading of the charge. This task is sufficiently well performed by a one- or multi-segment bottom plate (Fig. 19) with transverse ribs, which facilitate the above mentioned operation.

Metal bottom plates are also commonly used in medium-temperature chamber furnaces operating in the temperature range from 700 to 1000$^{o}$C. They shield the ceramic hearth of furnace, usually provided with a system of electric heaters. Plates are designed as monolithic or multi-segment castings (Fig. 19) of dimensions varying in the range of 300×600 mm up to 1000 ×3000 mm, and the weight from 20 up to even 600 kg. The charge is either put directly on the plates or is placed in the containers.

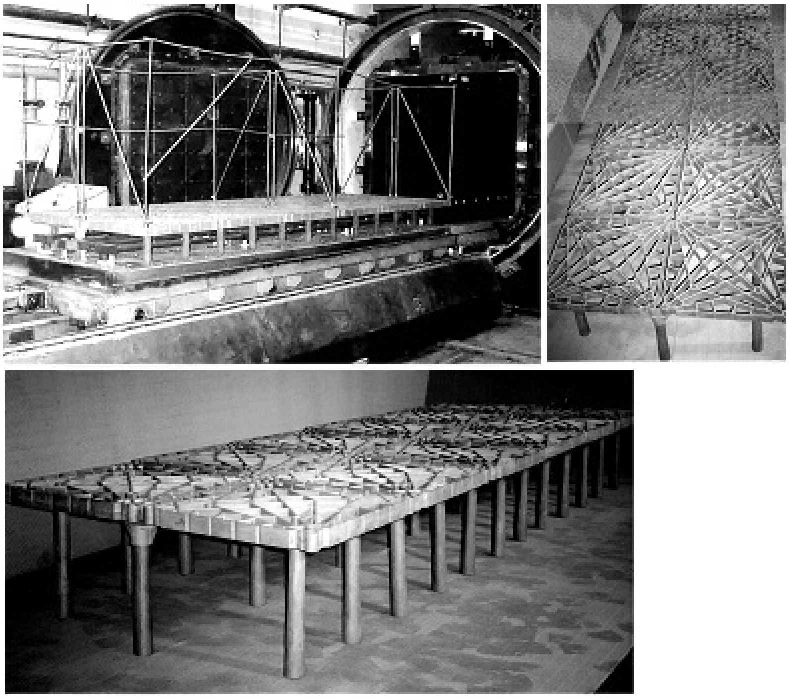

Fig. 17. A view of VWC 121036 vacuum furnace with bogie hearth made by SECO/WARWICK Świebodzin: a) general view, a construction of welded steel rods placed on the hearth indicates the space occupied by charge, b and c) base for the charge-holding containers placed on the furnace hearth and composed of pallets and racks cast from G-NiCr28W alloy, d) rack with mounted head whose pins hold pallets together

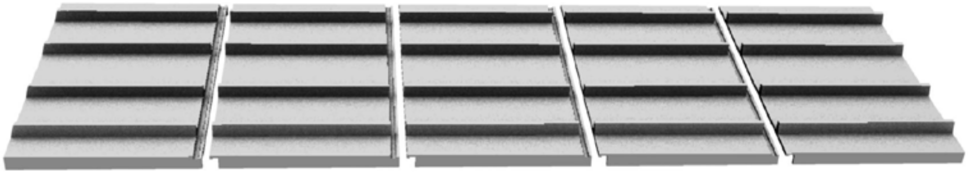

Fig. 18. Multi-segment bottom plate of a bogie hearth furnace cast from G-X40CrNiSi27-4 or G-X40CrNiSi25-20 alloys [5]

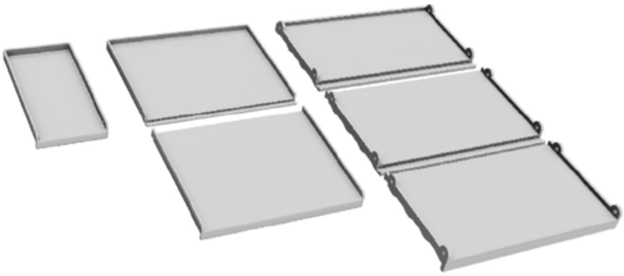

Fig. 19. Sketches of single- and multi-segment bottom plates operating in chamber furnaces made by SECO/WARWICK ThermAL SA [5]: materials: GX40CrSi24, GX40CrNiSi27-4 or GX40CrNiSi25-20

Selected fragments of the ceramic lining are also protected by castings other than the bottom plates. They vary in shape (Figs. 20 and 21) and are made as single-pieces or as segments connected together into one whole. The weight of single castings ranges from 20 to 150 kg [5].

## 2.4. Rotating elements (fans)

In the heating chamber of most of the heat treatment furnaces, air agitation devices are installed. Their task is to intensify the circulation of the atmosphere, which accelerates the homogenisation of its chemical composition within the entire chamber volume, making also the temperature distribution more uniform.

Depending on the task that the furnace is expected to perform and the size of its chamber, air agitators of different shapes and sizes made from different alloys are used (Fig. 22).

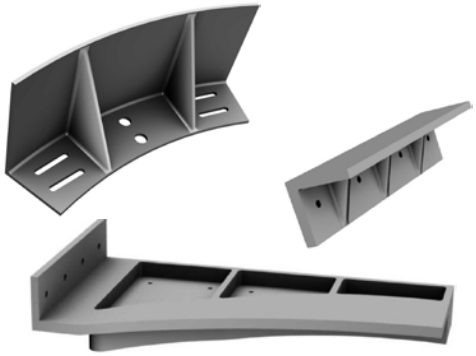

Fig. 20. Elements protecting the ceramic lining; sketches according to the documentation supplied by SECO/WARWICK SA Thermal and SECO/WARWICK Świebodzin [5]; material: GX40CrSi17 and GX40CrNiSi25-20

Fig. 21. Frame protecting the charging-discharging door [5]; material: GX40CrSi17

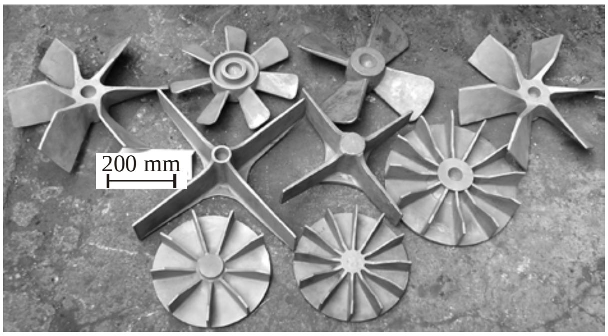


Fig. 22. Cast air agitators (fans) made by POLCAST Foundry for the following customers: SECO/WARWICK ThermAL SA, SECO/WARWICK from Świebodzin, RIVA from Międzyrzecz, and REMIX from Świebodzin [5]; material: GX40CrNiSi25-20, GX40NiCrSi35-17 and GX40NiCrSiNb38-19

# 3. Conclusion

Cast components are used in all types of the industrial heat treatment furnaces. The main types of alloys used for castings operating in the temperature range of 500-1250$^{o}$C are specified in the PN−EN 10295: 2002 Standard *Heat resistant steel castings*. At lower temperatures also cast corrosion-resistant steel and carbon steel are used.

The rules for the selection of chemical composition of the cast steel used for these elements, depending on the operating conditions, are widely described in the source studies [8, 9]. The principles of designing castings of this type are presented in [1, 10, 11].

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