Cast functional accessories for heat treatment furnaces

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Abstract

The study gives examples of the cast functional accessories operating in furnaces for the heat treatment of metals and alloys. The described design solutions of castings and their respective assemblies are used for charge preparation and handling. They were put in systematic order depending on furnace design and the technological purpose of heat treatment. Basic grades of austenitic cast steel, used for castings of this type, were enumerated, and examples of general guidelines formulated for their use were stated. The functional accessories described in this study were designed and made by the Foundry Research Laboratory of West Pomeranian University of Technology.

Keywords: Innovative foundry technologies and materials, Castings for heat treatment plants, Grates, Fixtures, Baskets

1. Introduction

Creep resistant metal parts (CRMP) operating in heat treatment furnaces can be divided into two general groups [1, 2]:
1. Construction elements. This group includes parts permanently fixed in a furnace, like retorts, radiant tubes, roller tracks, fans, and supports. The shape of these elements depends on function they are supposed to perform, while dimensions are directly related with the furnace size and type.
2. Functional accessories. This group includes the following parts: grates, fixtures, baskets, etc. Their shape mainly depends on the shape, size and number of the heat treated parts, while outer dimensions are adjusted to the shape and size of the furnace working chamber.

In most cases, CRMP are made from iron alloys of an austenitic matrix. In practical application, both cast and wrought alloys are used [1, 3-5].

Functional accessories (FA) form a group of several or several dozen cooperating elements, which vary in respect of their shape and size. Their main function is to create sufficiently similar conditions of heat treatment for the whole batch of charge placed in furnace chamber, as well as safe loading and unloading.

It is the shape of most of the FA that makes the casting process an optimum solution for their manufacture [7-11], although choosing of this process does not always guarantee the life of FA superior to parts made by other techniques. The choice of the process by which the individual elements included in FA will be made depends on the total outcome of an analysis, which takes into consideration the manufacturing cost, the expected life of elements on performance, the batch size, the mechanical properties of alloys, etc. [1].

This study describes the main types of FA with reference made to the classification of heat treatment furnaces, since both the configuration as well as the design principles of FA are closely related with the type of furnace in which the heat treatment will take place.

In this study, only cast FA are discussed. They have been made, or designed and made, by the Foundry Shop of West Pomeranian University of Technology in Szczecin during long-lasting scientific and technical cooperation with the domestic producers and users of heat treatment furnaces [6, 11-14].
2. Continuous puscher furnaces

Pusher furnaces are assigned for continuous operation. They are used in large-lot and mass production, especially for the process of carburising and carbonitriding. Properly designed FA are one of the most important factors deciding about the efficiency and reliability of the operation of these furnaces [1, 6, 9, 11÷19].

The main element of FA are base grates (Figs. 1 and 2a) of dimensions adjusted to the dimensions of the furnace hearth. On these grates, the remaining elements like intermediate grates, corner pillars and spacers (Figs. 1 and 2) are mounted. The shape and dimensions of the individual elements are usually adjusted to the assortment of heat treated products.

Both base and intermediate grates are openwork, thin-walled structures, usually having a square base (Fig. 2a, b). A typical grate has a side 450÷600 mm long and 30÷50 mm high. The weight is comprised in a range from 17 to 35 kg; the weight of total assembly (without charge) is up to 80÷150 kg. In a furnace, from several up to several dozen FA assemblies are operating at the same time.

Since individual elements of FA are replaceable, it is possible to carry out in one furnace the heat treatment of a charge in which individual pieces have different configurations and sizes. In most cases, the charge is composed of small and compact parts, usually of symmetrical geometry, like various gears, rollers, etc.

With the demand for mass heat treatment of parts of one type, the FA assemblies are designed and manufactured specifically for the heat treatment of these parts. The example of such design is shown in Figure 3a. The performance life of the assembly was tested at VW Motor Polska in Polkowice.
The assembly of overall dimensions of $640 \times 600 \times 838$ mm and a weight of 128 kg is composed of 66 cast parts joined together by welding. It can hold 30 pieces of camshafts for diesel engines (Fig. 3b).

3. Box furnaces

The family of furnace units characterised by a cuboid shape of the working space and intermittent operation comprises numerous different types of furnaces, starting with furnaces for annealing only, through the units assigned for toughening (vacuum furnaces included), and in traditional furnaces for the heat treatment under controlled atmosphere ending. The intermittent operation, relatively low labour cost in the case of small lot and piece production, the possibility to carry out heat treatment on products of different shapes and weights are the main advantages of furnaces included in this group [1, 7].

The majority of FA designs operating in chamber furnaces are units of a rectangular base.

The least intricate in design are the annealing furnaces without protective atmosphere. The charge for heat treatment is placed directly on a hearth plate installed on the furnace chamber bottom.

The hearth plates consist of one or several castings joined together (Fig. 4); their overall dimensions vary, ranging from $300 \times 600$ mm to $1000 \times 3000$ mm, or can be even larger, e.g. in high-capacity bogie hearth furnaces. The range of their overall weights is also very wide, i.e. from 20 up to even 600 kg. These are castings of straight design; smaller have smooth surfaces, larger are ribbed. They have relatively uniform wall cross-sections.

Nowadays, very fine and fine parts for the heat treatment are often placed in baskets to raise the furnace output and make loading and unloading easier. The interior part of basket is usually lined with chromium-nickel wire mesh.

Baskets are sometimes put on grates moving inside the furnace on roller tracks. The example of such design is shown in Figure 5. In an attempt to make the design as simple and functional as possible, the main grate for PeKat 2 furnace of dimensions $900 \times 600 \times 40$ mm is additionally provided with catches into which the four side walls are inserted, thus improving the stability of charge resting on the grate.

Typical designs of baskets allow to cast them either as one integral whole, or as several separate pieces joined together. Traditionally, in the latter case, the designer draws the base and four walls which are next assembled together with special locks, or with screws, or by welding (Figs. 5, 6). The chromium-nickel wire mesh or a perforated plate is placed inside the basket as a complementary element.

The design solutions used nowadays most frequently in chamber furnaces are the FA assemblies, which enable the charge to be placed on two and more levels (Figs. 7-11). This is possible due to the installation of intermediate grates with corner pillars and spacers of proper length, adjusted to the dimensions of the heat treated charge components (Fig. 9).
Fig. 5. Base grate for PeKat 2 furnace completed with side walls [6]

Fig. 6. Basket for loose stacking of parts; dimensions: 900×600×145 mm [6]

Fig. 7. A four-level assembly for vacuum furnace [6]

Fig. 8. A two and more level assembly moving on a roller track in PeKat 1 furnace [6, 15]

Fig. 9. Multi-level assemblies with corner pillars and spacers [6]

Depending on the overall size of the furnace chamber and on the size and number of the heat treated objects, the overall dimensions of the designed assemblies can vary within a wide range of values from the traditional designs based on standard grates of 900×600 mm dimensions (Fig. 8) up to smaller units with the base of 600×300 mm dimensions (Fig. 7). In each case it is possible to increase the charging capacity of the assembly using additional intermediate grates and corner pillars with spacers (Fig. 9).

The capacity of FA assemblies is also increased by designing the units with properly shaped slings (Fig. 10); this solution not only enables hanging or laying the heat treated parts of different configurations but also provides additional space between them demanded by the technological regime (Fig. 10b). Slings similar to those depicted in Figure 10b are also used in FA assemblies operating in pusher furnaces (Fig. 1).

Apart from the versatile design of FA assemblies operating in chamber furnaces, i.e. the assemblies designed for the heat treatment of various charge assortments, also in this case (like in the case of pusher furnaces), the assemblies for the heat treatment of one homogeneous product series are designed and made. Examples of such assemblies are shown in Figures 11 and 12.

The first of the two FA assemblies has the overall dimensions of 1170×870×600 mm.
A large group of the users of FA assemblies are the enterprises using baskets for the casting annealing process (Fig. 13). The first basket (Fig. 13a) has the dimensions of 1050×870×600 mm and a total weight of 200 kg. It is assigned for the heat treatment of fine ductile iron castings lying loose in the basket. The second basket (Fig. 13b) (1520×1380×650 mm, 440 kg) has been designed for an ordered arrangement of the aluminium gearbox housings, placed in special compartments. Once inside the furnace, it can be rearranged into a multi-level structure. Both structures include cast elements, additionally joined by welding and fixed with screws.
Fig. 12. An assembly for the heat treatment of shafts operating at ZZN HSW in Stalowa Wola [6, 16]:
a) general view, b) charge position

Fig. 13. Baskets for the heat treatment of castings [6]: a) basket for operation in bogie hearth furnace (composed of 12 cast elements),
b) basket for operation in roller pusher furnace (composed of 32 cast elements)

4. Pit furnaces

The outer shape of FA assemblies operating in pit furnaces is adjusted to a cylindrical outline of the furnace working chamber. The tightness of the chamber makes furnaces of this type useful for all types of the heat treatment carried out under controlled atmosphere. Like the previously mentioned pusher and chamber furnaces, pit furnaces are also commonly used in the machine building industry. Elongated shape of the working chamber makes them particularly suitable for the heat treatment of long objects that should keep vertical hanging position throughout the entire technological process [7].

A typical FA assembly comprises a central vertical rod on which grates are mounted in a horizontal position suitable for laying/hanging of charge (Fig. 14). The upper part of the rod ends in an eye to facilitate transport of the whole assembly. Depending on the shape, size and quantity of heat treated parts, additional intermediate grates are installed in the assembly (Fig. 14). The assembly presented in Figure 14 consists of 57 cast elements, which include 8 grates and 49 internal and external bushings. The space between the grates can be filled with extra slings to
facilitate a uniform distribution of charge elements and to ensure a relatively uniform circulation of the atmosphere.

Fig. 14. FA assembly with charge (bearing rings) placed on intermediate grates for heat treatment [6]; dimensions: Ø1200×2400 mm, weight: 1000 kg

The simplest, although nowadays rather rarely used, FA assembly consists of a basket made from two cast elements (Fig. 15). Structures of this type can have overall dimensions of up to Ø600×400 mm (the basket diameter is adjusted to the average dimensions of the furnace working chamber) and a weight of up to 100 kg. The charge is lying loose in the basket. Usually, in the furnace, several baskets are operating at the same time.

Fig. 15. Pit-furnace basket [6]: removable bottom (1) and housing (2)

The cylindrical outer shape of FA assemblies is also suitable for furnaces other than the pit furnaces. Figure 16 shows the example of an assembly designed for operation in a hood-type furnace (dimensions: Ø1200×1200 mm, weight: 280 kg). It consists of 261 castings; in this number 192 pieces are slings, which enable separate hanging of heat treated parts.

Fig. 16. A multi-level FA assembly operating at AVIO Polska in Bielsko-Biała for the heat treatment of rotor blades for Boeing 777 turbojet engine [6]

More details about the basic rules to design castings discussed in this study are disclosed in [9÷11, 18, 19].

5. Chemical composition of cast steel

Table 1 compares the grades of creep-resistant austenitic cast steel covered by respective European Standard, commonly used for the construction of heat treatment furnaces. Obviously, this comparison does not cover all cast alloy grades used by different producers of FA (e.g. [8]); it indicates only the main variations.

The decision concerning the choice of a specific cast steel grade for FA depends on the heat treatment parameters and on the weight of parts placed on the FA assembly. The heat treatment process includes the following basic parameters:

1. Process temperature. This parameter is responsible for the following classification of furnaces: low-temperature (≥700°C), medium-temperature (700÷1000°C) and high-temperature (<1000°C). Knowing properties of the individual cast steel grades, it can be generally stated that FA for the furnaces included in the first group should be made from alloys 1÷4, possibly up to 7. For the second group, items 5÷14 are most appropriate, while for the third group of
furnaces, the remaining cast steel grades are used, providing the furnace operating temperature is up to 1250°C.

Table 1.
Grades of creep resistant austenitic cast steel according to EN 10295:2002

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>GX25CrNiSi18-9</td>
</tr>
<tr>
<td>2.</td>
<td>GX40CrNiSi22-10</td>
</tr>
<tr>
<td>3.</td>
<td>GX25CrNiSi20-14</td>
</tr>
<tr>
<td>4.</td>
<td>GX40CrNiSi25-12</td>
</tr>
<tr>
<td>5.</td>
<td>GX40CrNiSi25-20</td>
</tr>
<tr>
<td>6.</td>
<td>GX40CrNiSiNb24-24</td>
</tr>
<tr>
<td>7.</td>
<td>GX35NiCrSi25-21</td>
</tr>
<tr>
<td>8.</td>
<td>GX40NiCrSi35-17</td>
</tr>
<tr>
<td>9.</td>
<td>GX40NiCrSiNb35-18</td>
</tr>
<tr>
<td>10.</td>
<td>GX40NiCrSi38-19</td>
</tr>
<tr>
<td>11.</td>
<td>GX40NiCrSiNb38-19</td>
</tr>
<tr>
<td>12.</td>
<td>GX10NiCrNb32-20</td>
</tr>
<tr>
<td>13.</td>
<td>GX40NiCrSi33-26</td>
</tr>
<tr>
<td>14.</td>
<td>GX40NiCrNb35-26</td>
</tr>
<tr>
<td>15.</td>
<td>GX30NiCrCo20-20</td>
</tr>
<tr>
<td>16.</td>
<td>GX50NiCrCoW35-25-15-5</td>
</tr>
<tr>
<td>17.</td>
<td>GX40NiCrNb45-35</td>
</tr>
</tbody>
</table>

2. Type of atmosphere. In the process of carburising or nitriding, one should allow for the risk of quick degradation of the FA parts caused by high-temperature corrosion and thermal fatigue. Good resistance to the effect of these factors can offer alloys with high content of Ni, Si and Nb – e.g. alloys 8÷11 (Tab. 1). On the other hand, when the atmosphere contains high sulphur content, alloys with high content of Cr and low content of Ni should be selected, e.g. alloys 2÷4.

3. The weight of FA and their loading capacity. The weight of FA assemblies can reach 50 and more percent of the charge weight, and therefore it affects directly the run and output of the heat treatment process. Making castings from alloys of possibly high creep resistance (in practice it means the use of low content of the alloying elements, e.g. alloys 8÷17, Tab. 1) enables reducing the casting wall cross-section, and hence the weight of the whole FA assembly or, when preserving the original casting wall cross-section, it enables increasing the charge weight. For example, each kilogram subtracted from the casting enables savings of about 36€/year on account of savings in the heating energy only [19]. However, the wall cross-section of the FA assemblies depends not only on the maximum charge weight but also on the minimum thickness demanded by the applied casting technique, i.e. the minimum cross-section of foundry mould cavity necessary for its proper filling with metal [11].

The recommendations formulated above are but only a part of the analysis that should be carried out before final decision on the best grade of the used cast steel is taken. The decision also depends on other factors, e.g. on users’ requirements concerning life of the FA assemblies, as well as widely understood properties of other elements cooperating with FA in a technological line [1, 11].

References