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Casting of Hearth Plates from High-chromium Steel

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Abstract

The paper presents the results of studies on the development of manufacturing technologies to cast hearth plates operating in chamber furnaces for heat treatment. Castings made from the heat-resistant G-X40CrNiSi27-4 steel were poured in hand-made green sand molds. The following operations were performed: computer simulation to predict the distribution of internal defects in castings produced by the above mentioned technology with risers bare and coated with exothermic and insulating sleeves, analysis of each variant of the technology, and manufacture of experimental castings. As a result of the conducted studies and analysis it was found that the use of risers with exothermic sleeves does not affect to a significant degree the quality of the produced castings of hearth plates, but it significantly improves the metal yield.

Keywords: Innovative technologies and materials, High-chromium steel castings, Heat insulating sleeves for risers, Hearth plates

1. Introduction

Plate-shaped cast structures are widely used in industry. They serve as machine bases, lids, partition walls, or bottoms [1]. Hearth plates are a good example of castings from the latter group. They protect the hearth of the heat treatment furnaces from damage and are most commonly used in low- and medium-temperature furnace units. Typical hearth plate has a rectangular shape and constant thickness, or it is ribbed underside (Fig. 1a). It may be homogeneous or composed of segments in sizes from 300×600 to 500×1000 mm, with wall thickness of 10–25 mm and a weight of 20–100 kg [2]. Plates are made from the following cast steel grades: GX40CrSi28 (1.4776), GX130CrSi29 (1.4777) or G-X40CrNiSi27-4 (1.4823) – all according to EN 10295:2002. The plate during operation is loaded with a charge and exposed to the effect of high temperature (max 1000°C) with access of the atmospheric air.

The mere shape of the plate is the source of problems commonly encountered during manufacture. It is the presence of surface defects that require labor-intensive repairs, including grinding, hardfacing and annealing [2]. Typical defects are shrinkage depressions (W-206), folds (W-207) and slag inclusions (W-405) (Fig. 1b, c). Internal defects are also identified such as shrinkage porosities (W-404) or shrinkage cavities (W-403) (PN-85/H-83105).

At the stage of the casting technology development, the thin-wall plate design usually requires practical application of the principle of simultaneous solidification. At the same time, owing to a multi-point support provided to the plate when it is resting on the furnace hearth, the question how rigid the walls of the cast plate will be during operation is not so important. Ribs are introduced to the design mainly to reduce the casting weight.

Castings made of high-chromium steel are characterized by a strong tendency to the formation of coarse grain structure, which also enhances the general tendency to the formation of shrinkage porosities. A similar effect occurs when molds are poured with metal at a temperature too high, which in this group of castings is the decision often taken in industrial practice. Simultaneous solidification is another factor that increases the volume fraction of the shrinkage porosity [3].

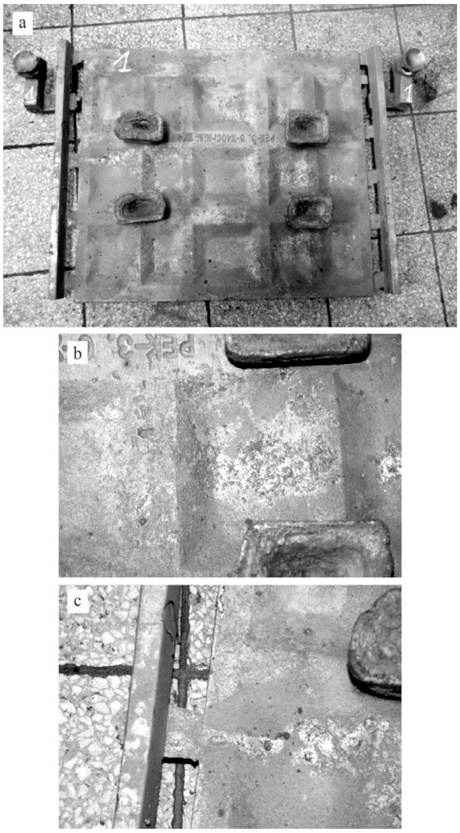

Fig. 1. Casting of 730×620 mm hearth plate weighing 50 kg; top view [2]: a) casting with the gating system, b) slag inclusion found on the casting surface between risers, c) slag flowing through ingate into the mold cavity.
Cast material: G-X40CrNiSi27-4

This work is a continuation of earlier studies [2] devoted mainly to the elimination of slag inclusions from cast plates through the use of ceramic foam filters. The present studies focus on an assessment of the effectiveness of risers and on the methods to increase metal yield in the process of the hearth plate manufacture due to: the use of risers coated with insulating and exothermic sleeves, and mold pouring through risers eliminating at the same time the gating system.

2. Research methodology and test results

At the beginning of studies it was assumed that application of insulating sleeves should not result in the need to introduce any major adjustments to the so far used technology (Fig. 1a). The shape and dimensions of the gating system were chosen by numerous experiments, the aim of which was also to protect the casting from deformation during cooling in mold.

The history of the cast steel melting, the materials used for molds and the molding process itself were discussed in [4].

In the casting (Fig. 1a), at least eight hot spots located in the area of intersection of the ribs should be indicated. However, it was decided to introduce only four risers (Fig. 1a) and locate them in the areas where in casting made without the use of risers, shrinkage depressions were formed on the surface. Due to the operating conditions of the plate, it was considered that in other areas the presence of small shrinkage depression in the plate wall axis could be treated as an allowable defect, since the zone with this defect is located in the region of minimum operational stress.

The distribution of internal defects in castings was evaluated based on computer simulation results (Figs. 2 and 3).

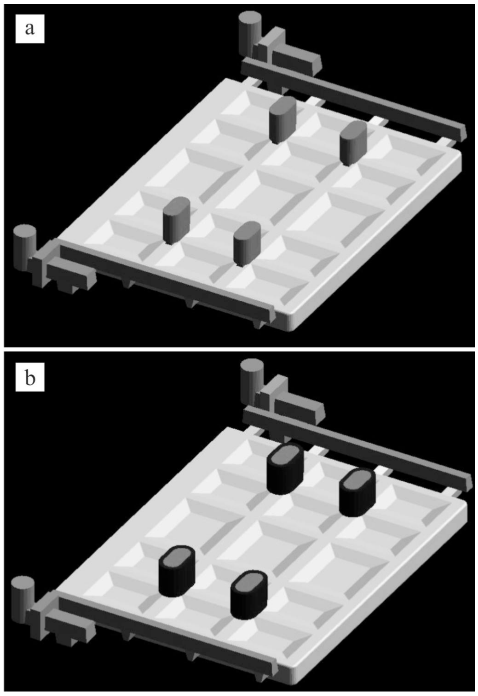

Fig. 2. Geometric configuration of models tested [4]: a) with conventional risers, b) with insulated risers

In the analyzed variants of the manufacturing technology, risers with SIBIRAL insulating sleeves (Fig. 3b) and KALIMINEX 2000 exothermic sleeves (Fig. 3c) were used. The application of each type of the sleeve was accompanied by suitable adjustments introduced to the riser dimensions.

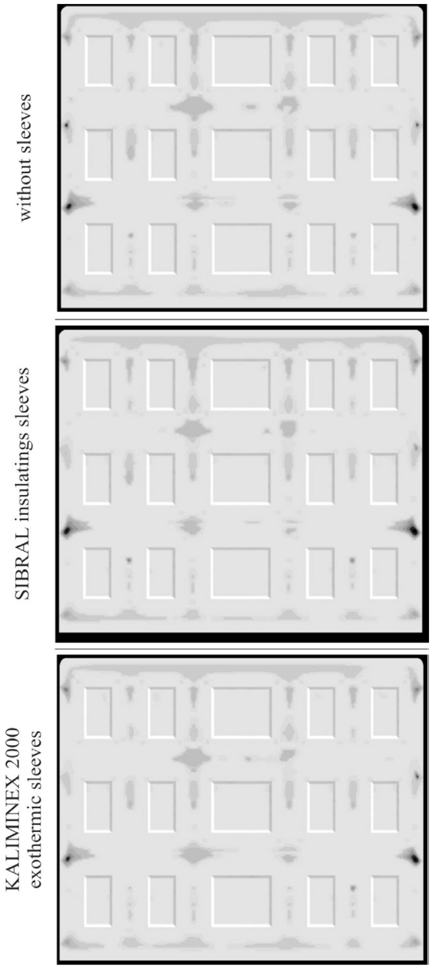

Fig. 3. Predicted occurrence of defects in the plate shown in Figure 2 cast with and without different insulating sleeves [4]

The results of simulation (Fig. 3) allowed drawing the following conclusions:

– compared to traditional technology, the introduction of an insulating or exothermic sleeve does not significantly alter the predicted occurrence of shrinkage defects. There is a risk of porosity or shrinkage porosity occurrence in thicker sections of the plate, with the highest probability of metal deficiency occurring near the ingates. The maximum value of metal deficiency in the rest of the casting volume is expected not to exceed 7%, thus the resulting shrinkage defects should not pose a serious threat to the casting quality, in accordance with the assumptions made previously;
– the dimensions and the shape of ingates require some adjustments due to the risk of macroporosity formation (apparent voids and shrinkage cavities) in casting in the places where metal is fed to the mold cavity.

Generally it can be assumed that the applied casting technology eliminates the macroporosity defects from the casting structure; the only exception are the regions in casting directly connected with the ingates.

The next step in the implementation of technology for casting of hearth plates was practical demonstration of the experimental results and determination of metal yield obtained in the casting manufacturing process using bare risers and insulated risers. The task was executed by making castings in three different variants:

1. With the gating system and four risers without insulation (Fig. 4a). This variant was adopted as a reference point for the quality assessment of other variants.
2. With the gating system and four risers coated with SIBIRAL insulating sleeves (Fig. 4b).
3. Without the gating system, which was replaced by two risers coated with the KALIMINEX 2000 exothermic sleeves. These risers also served as ingates. Risers were provided with the 10 PPI Ø70×25 mm filters and their height was additionally increased using 75 mm hot tops filled with the molding sand (Fig. 5a and b). In the four remaining risers (Fig. 5b), the same KALIMINEX 2000 exothermic sleeves were used.

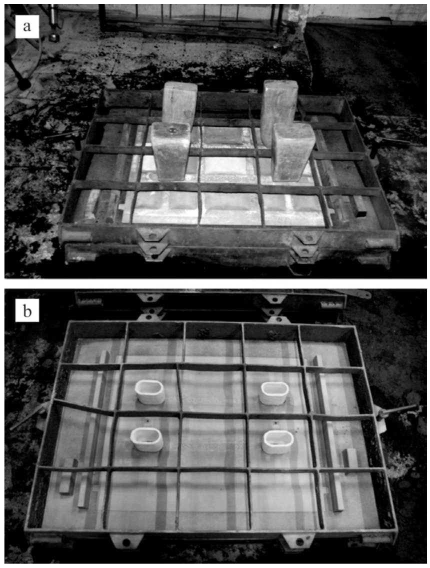

Fig. 4. Lower half mold during casting of hearth plate shown in Figure 1 using bare risers (a – variant 1) and risers with insulating sleeves (b – variant 2) [4]

After knocking out from molds, the castings were fettled and weighed; their surface and selected sections were examined to check the obtained quality and stability of dimensions [4].

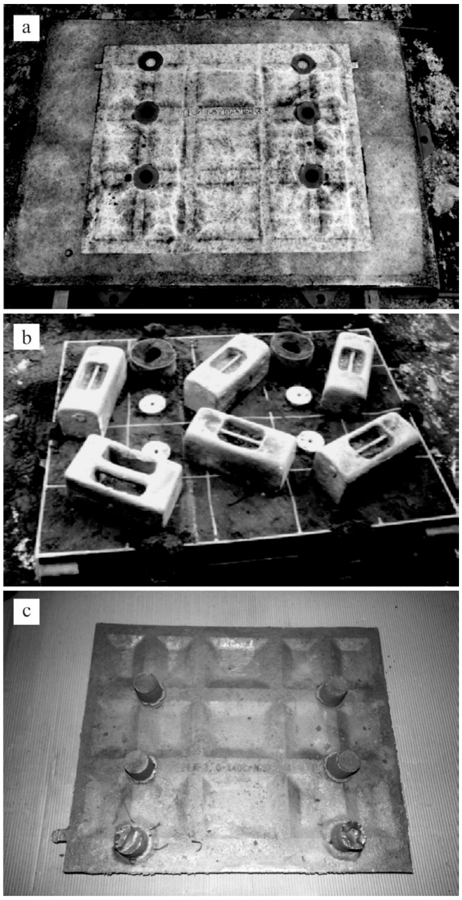

Fig. 5. Variant 3 – lower half mold during casting of hearth plate shown in Figure 1 (a), assembled mold ready for pouring (b), and raw casting (c) [4]

The yield of metal (U) was determined from equation (1):

$$U = (M_S / M_M) \times 100, \% \quad (1)$$

where: M_S – the mass of raw casting, M_M – the weight of metal poured into a mold.

The following values of U were obtained for individual variants of the hearth plate casting process: 1 – 66%, 2 – 72%, and 3 – 87%.

The inspection of casting surfaces and sections has confirmed that the level of both external and internal defects does not deviate from the value assumed in the initial phase of the experiment. Casting produced according to variant 3 suffered warping (Fig. 6).

Variant 2 of the technology (the use of gating system and four risers coated with SIBIRAL sleeve) – allowing for other factors affecting the efficiency of the plate production such as work input during manufacture of molds, the cost of casting fettling, and tool wear – was the most preferred one for the technical conditions under which the casting producer was operating.

Fig. 6. Plate bent along the short side – variant 3 [4]

3. Conclusions

Based on the results of the study it should be noted that the use of risers with insulating / exothermic coating in the manufacture of hearth plates cast from the G-X40CrNiSi27-4 steel significantly increases the metal yield. As long as this statement is of a qualitative nature only, it does not add anything new to the theory and practice of the use of risers, telling only the truth that is rather obvious to anyone skilled in the art. On the other hand, quantitative information provided together with the proposed variants of technology is of a practical and therefore useful character. At the same time, one has to remember that the choice of technology used for the manufacture of castings has always an individual character. It combines the desire to find and apply the solution that will be optimal from both technical and economic point of view.

Another conclusion that comes to our mind is that the designer and user of cast products should sometimes consciously tolerate some imperfections that occur in the material. In the case under discussion it is the presence of microporosities in the casting structure.

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