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The Effect of Pallet Component Geometry on Temperature Gradient During Cooling

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Abstract

The paper discusses the impact of the geometry of foundry pallet components on the value of temperature gradient on the wall cross-section during heat treatment. The gradient is one of the most important factors determining the distribution of thermal stresses in these items. Analysis of quantitative simulation was carried out to detect possible effect of the type of connection between pallet walls and thickness of these walls (ribs) on the interior temperature distribution during rapid cooling. The analysis was performed for five basic designs of wall connections used in pallets. Basing on the results obtained, the conclusions were drawn on the best connection between the ribs in foundry pallets.

Keywords: Application of information technology to the foundry industry, Pallet, Temperature gradient

1. Introduction

The conditions to which parts of the technological equipment operating in carburizing furnaces, foundry pallets included, are exposed, have a very negative impact on the service life. The factor particularly dangerous is an abrupt change in temperature which occurs during cooling of the charge. This also refers to the equipment on which the charge is resting. During rapid cooling, in the palette, severe micro- and macrostresses are formed [1-4], resulting in the appearance of deformations and cracks. The value of thermal macrostresses is directly related to the temperature gradient on the cross-section of the cooled element.

A significant impact on this gradient exert such factors as: the maximum temperature of the operating cycle, the type and temperature of the cooling medium, the thermal properties of the palette material, and the dimensions of palette walls as well as the type of connection made between them. Since heat treatment parameters are preset, and the choice of the available cast materials for palette components is limited, the designer of the furnace tooling can typically minimize the generated stresses through changes introduced to the geometry of palette design. In the literature [1-3] one can find information on the principles of designing the cast components which are expected to operate under the cyclic changes of temperature. This is, however, only qualitative information. There are no clearly defined numerical criteria based on which one could choose the optimum solution.

The aim of the conducted study was to obtain quantitative results regarding the effect of foundry pallet components geometry on the value of temperature gradient in the palette wall cross-section during subsequent stages of cooling. The numerical analysis was based on the finite element method. The necessary calculations were made with the use of Nei Nastran software.

2. The effect of wall thickness on temperature gradient

One of the most important technological parameters of foundry pallet (Fig. 1) is the thickness of its walls. The value of this parameter should be chosen in such a way as to make the process of palette casting as easy as possible, ensuring at the same time that the ready casting meets the strength requirements with a minimum own weight and the smallest possible temperature differences occurring in each of its sections. It is the fact widely known that, due to a temperature gradient formed in the cross-section of the cooled element, the thickness of the walls should be as small as possible. On the other hand, from the point of view of the mechanical strength of the pallet, heavier wall cross-sections are obviously preferred. Therefore, thickness of the palette walls can not be reduced in any arbitrary way, since it is controlled by the need to provide adequate mechanical strength. Hence it follows that, besides qualitative analysis, also a quantitative analysis is necessary to support the choice of optimum solution. In this study, a simulation was carried out to evaluate the impact of the cast palette wall thickness (the thickness of vertical ribs) on temperature gradient in the wall cross-section at the time of cooling.

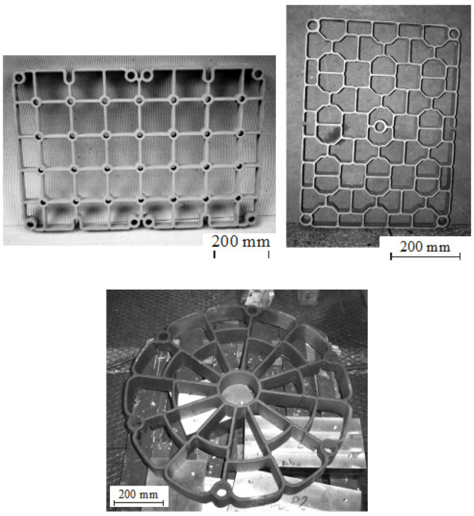

Fig. 1. Sample solutions of pallet design [2]

In the analysis, a model of the rib with dimensions of 80·50·*d* mm was adopted, where *d* is the thickness of one rib. The range of the thickness values (6 to 12 mm) was selected in such a way as to reflect the actual values used in industrial applications. A sketch of the rib is shown in Figure 2. In analysis the following data were used [5, 6]: the palette material − cast steel 1.4849, the thermal conductivity λ of cast steel – in accordance with the standard [5], specific heat c = 500 J / (kg · K), the coefficient of heat transfer − determined in accordance with the procedure described in [7]. Cooling from the temperature T_0 = 900°C was carried out in oil at 60°C.

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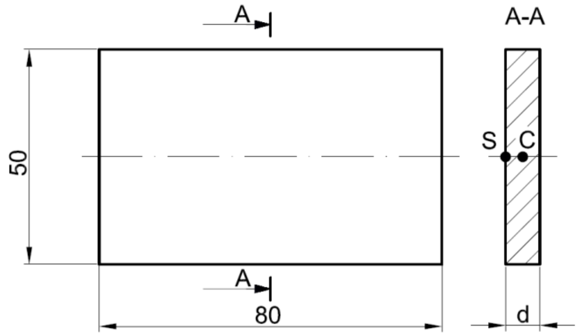

Fig. 2. Dimensions of palette ribs

Figure 3 shows temperature changes in the internal part and on the surface of the rib having a thickness d = 8 mm in the first three seconds of the cooling process, while Figure 4 summarizes graphs showing temperature changes inside the rib (point *C* according to designations in Figure 2) during that time for different values of the dimension *d*. Figure 5 shows the maximum temperature difference (ΔT_{max}) and the difference after one and two seconds from the start of the cooling process, measured between the center (*C*) and the surface (*S*) of the cooled ribs.

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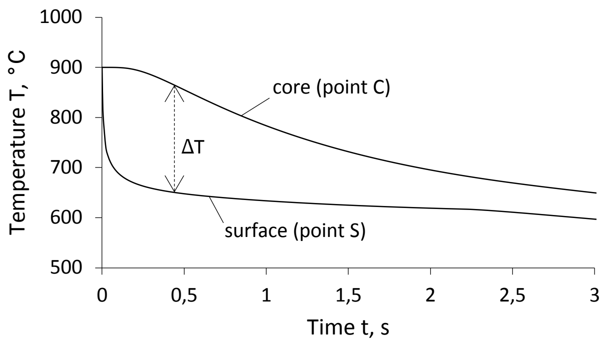

Fig. 3. Temperature changes on the surface and in the middle of the cross-section of an 8 mm thick rib during cooling

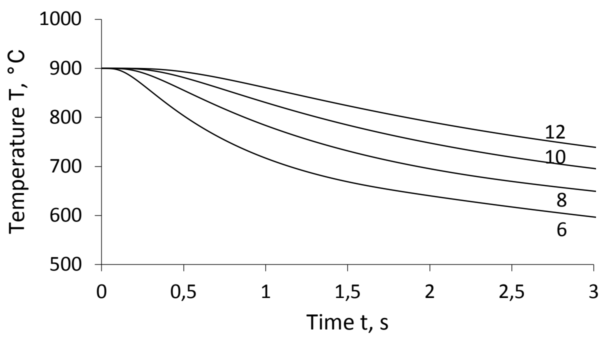

Fig. 4. The effect of wall thickness on temperature change inside the rib wall (point *C*) during cooling

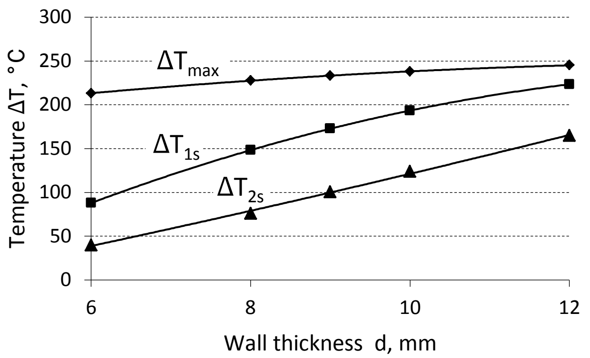

Fig. 5. The effect of wall thickness on temperature difference during cooling of a vertical rib

From the presented graphs it can be seen that wall thickness significantly affects the size of the temperature gradient between the surface and the center of the rib, this impact being most evident in the time lapse during which large temperature differences occur. In the examined example of the rib with a wall thickness d = 6 mm, after one second, the temperature difference between the center and the surface was only 41% of the maximum difference ΔT_{max}, while in the rib with a wall thickness d = 12 mm, this difference was 91% of ΔT_{max}. After two seconds, the difference was 19% and 67%, respectively. So it can be supposed that longer times of the occurrence of high temperature gradients in the cross-sections of the walls of the cooled ribs will be reflected in higher values of the thermal stresses formed during cooling.

3. The effect of wall connection on temperature gradient

In considering the question of the impact of wall thickness on temperature gradient it should be noted that the solution particularly disadvantageous is that where the thickness has different values at different places in the pallet. If this is the case, so called hot spots are formed. In addition to temperature gradient between the wall center and surface, another temperature gradient is formed between various points inside the casting, lying in planes parallel to the wall surface, thus promoting the formation of additional stresses.

The example of places where the wall thickness regularity is disturbed is a connection formed between several walls. In such places, when the pallet is cast, the risk of internal defects of the shrinkage porosity or contraction cavity type is increasing [1], and during the palette operating cycle, a large number of cracks is formed there. Therefore the decision concerning proper selection of the type of palette wall connections, for which the designer is responsible, is crucial for the pallet stability.

There are numerous design solutions of wall connections used in foundry pallets. The most common types of connections are: X, Y, T (Fig. 6). In T and Y type connections, to reduce the occurrence of hot spots, the recommended solution is to make technological recesses (Figs. 6d and 6e). FEM models of the connections used in calculations are shown in Figure 7.

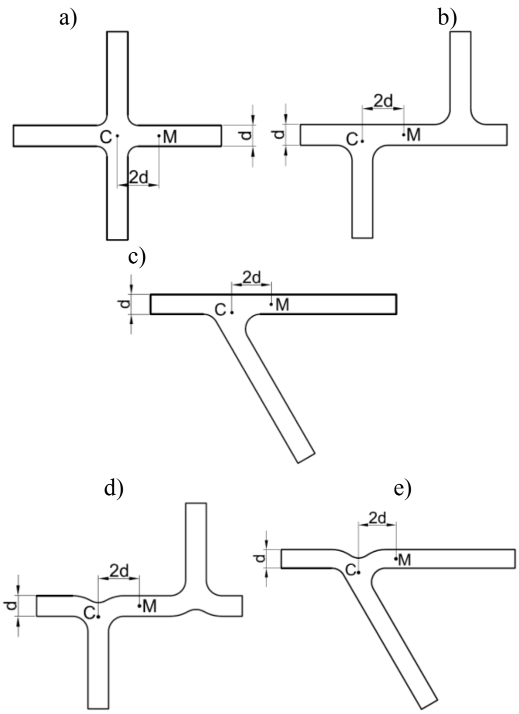

Fig. 6. Connections between pallet walls with indicated location of the measuring points (C, M): a) X, b) double T, c) Y, d) double T with recess, e) Y with recess

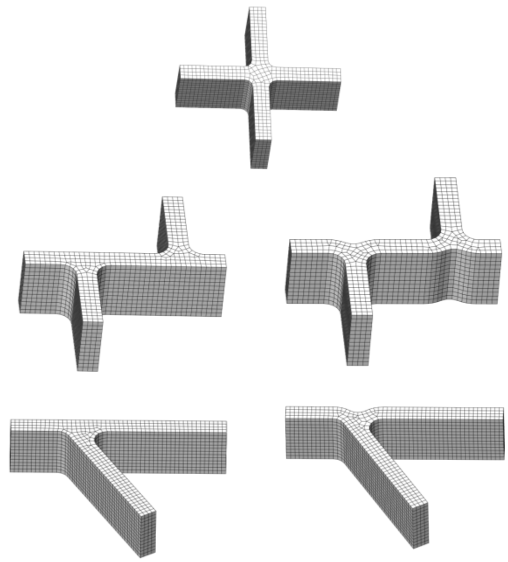

Fig. 7. Finite element mesh

In the performed analysis, a criterion for comparison was the difference in temperature between the center of the connection (point C according to designations in Figure 6) and point M lying in the middle of cross-section of the rib in a plane distant by two wall thicknesses from point C. As a basic wall thickness, the thickness of 8 mm was adopted and the fillet radius r = 6mm was applied. The properties of cast material and process parameters were the same as in previous studies.

The results obtained are set out in a graph in Figure 8. It depicts changes in temperature difference between the test points *C* and *M* for each of the examined types of connections. Table 1 summarizes the highest temperature differences recorded between these points for each type of connection.

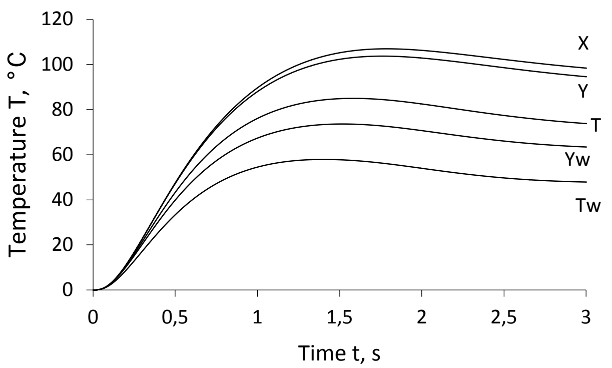

Fig. 8. Changes in the temperature difference between points *C* and *M* for various types of connections

Table 1.
Maximum temperature differences between points *C* and *M*

Type of connection	X	T	T_w	Y	Y_w
max Δ*T*, °C	107	85	58	104	74

From the comparisons made in Figure 8 and Table 1 it follows that the largest temperature differences arise in X and Y type connections without recesses. In unmodified connections, the best solution is the T type connection.

The presented results clearly show how strongly temperature gradient depends on the uniform wall thickness obtained by making the technological recesses. In both Y and T type connections, making wall thickness uniform allowed reducing the temperature gradient by approximately 30%. This can have a significant impact on the formation of thermal stresses during heating and cooling of palette, and consequently on the performance life of this palette.

4. Summary

Studies have quantitatively confirmed the significant impact of palette components geometry on temperature gradient in the cross-section of these components during cooling cycle, and thus on the formation of thermal stresses during this cycle. It means that by shaping the geometry of pallet components, the designers can, to a considerable extent, influence the generation of thermal stresses during the palette operation cycle.

Using the wall thickness parameter it becomes possible to control the time lapse during which the high temperature gradient is maintained in the palette wall. In the case of ribs, the use of X type connections should be avoided. If a connection of this type is necessary, the design should be modified so as to replace it with the double T connection. In the case of T and Y connections, recesses should be made to keep the wall thickness uniform and reduce thermal stresses. Potential savings that can be achieved by casting a component without recesses will be nullified by the resulting casting defects and faster formation of cracks excluding the palette from further operation.

The results obtained show the significance of quantitative analysis of technological solutions used in foundry pallets. Further analysis should focus on studies of the distribution of temperature and thermal stresses in larger areas forming important fragments of the structure of pallets and in pallets considered as one whole.

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