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THE INFLUENCE OF BURNER LOCATIONS IN THE HEATING FURNACE ON THE CHARGE TEMPERATURE FIELD

WPŁYW USYTUOWANIA PALNIKÓW W PIECU GRZEWCZYM NA POLE TEMPERATURY NAGRZEWANEGO WSADU DO PRZERÓBKI PLASTYCZNEJ

Charge heating in industrial furnaces is a difficult and complex process. There are many physical phenomena which influence heat transfer. At the charge surface heat transfer takes place by radiation and convection. In order to ensure correct operation of the technological system, it is necessary to achieve the required charge temperature in the whole volume and ensure its uniformity.

The influence of selected burner locations inside the furnace on the charge temperature has been analysed. The temperature field and its uniformity in the round charge made of steel for hot open die forging have been analysed. The model and numerical calculations were performed with the ANSYS-Fluent 14.5 package.

Keywords: industrial furnaces, heat transfer, numerical modelling,

Nagrzewanie wsadu w piecach przemysłowych jest trudnym i złożonym procesem. Celem zapewnienia prawidłowej pracy ciągu technologicznego konieczne jest osiągnięcie przez wsad wymaganej temperatury w całej objętości, oraz zapewnienie odpowiedniej równomierności nagrzewania.

W pracy określono wpływ sposobu nagrzewania wsadu w piecu komorowym dla wybranych wariantów usytuowania palników grzewczych. Analizie poddano pole temperatury i jego jednorodność w nagrzewanym wsadzie stalowym przeznaczonym do przeróbki plastycznej. Model i obliczenia wykonano pakietem numerycznym ANSYS-Fluent 14.5.

1. Introduction

Charge heating for open die forging is among the most important stages of the final product manufacturing. The problem of a uniform temperature field in the ingot that is heated is important in the production process. The heating in the furnace is a difficult and complex process. There are many physical phenomena which influence heat exchange. Heat transfer occurs by radiation and convection between the furnace and the surface of the charge. In order to ensure the correct operation of the technological system, it is necessary to achieve the required temperature in the whole volume of the charge and ensure its uniformity. Modelling of the temperature field and other phenomena as regards the process of steel production has been analysed by several authors, with both commercial software and original formulations having been applied [1-8].

The performance of heating furnaces can be controlled by the proper definition of the heating time and the furnace temperature profile. The temperature distribution in the furnace is limited by the design features of the furnace, the shape and dimensions of the charge and the physical properties of the heated material. An incorrect selection of these parameters may cause incorrect heating of the charge, disrupt the operation of the furnace or prolong the heating time which, in turn, can contribute to an increase in the energy consumption and a reduction of the furnace efficiency [9-15].

The influence of selected configurations of the heating burners in the furnace on the charge temperature has been analysed. The temperature field and its uniformity in the heated round steel charge for hot open die forging have been analysed. The model and numerical calculations were performed with the ANSYS-Fluent 14.5 package.

2. Heat transfer models

The determination of the charge temperature field requires solving the heat transfer equation of the charge volume for the prescribed heat transfer boundary conditions resulting from the furnace atmosphere and the furnace walls. The heat transfer between the charge surface and the furnace atmosphere occurs by radiation and convection. In order to fully describe the heating furnace operation model,

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it is necessary to describe the heat transfer by its structural components - the walls and fluid composed of combustion gases. Such a comprehensive approach to the model construction makes the results of the numerical calculations accurate, taking into account the most important factors which influence the charge heating in the chamber furnace. Neglecting convection in the furnace chamber leads to an underestimation of the heat flux on the surface of the heated charge [16].

In order to accelerate the computations, a two dimensional (2D) model was applied, allowing the temperature in the cross-section of the charge placed in a chamber furnace to be determined [17].

$$\lambda\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right]+q_v=\rho\, c_p\frac{\partial T}{\partial \tau} \tag{1}$$

where:
c_p – specific heat, [J/(kg K)]
q_v – efficiency of the internal heat source, [W/m^3]
x,y – Cartesian coordinates, [m]
λ – heat transfer coefficient of the charge, [W/(m K)]
ρ – charge density, [kg/m^3]
τ – time [s]

The solution of the equation (1) is a time dependent temperature field $T\ (x,\ y,\ \tau)$, which should meet the boundary conditions at the surface of the material heated. The boundary conditions were determined on the basis of the adopted heat transfer mechanisms: prevailing radiation and supplementary convection related to the movement of hot combustion gases in the furnace chamber. The model of Conjugate Heat Transfer for Fluid/Solid interfaces [18] has been used in the calculation. The Discrete Ordinates (DO) [18] model of radiation heat transfer implemented in the numerical package was used in the calculations, whose Angular Discretization takes on the following values: Theta Divisions – 2, Phi Divisions – 2, Theta Pixels – 1, Phi Pixels -1. Other values of those parameters have been considered during the research. The constant value of the emissivity of the charge surface and furnace walls amounting to 0.83 and 0.3 respectively has been taken. The combustion gases flow was described by the standard turbulence model k-ε using Standard Wall Function [18]. The following constant values have been assumed for this model:: C_{mu} = 0.09, C_1 =1.44, C_2 = 1.92 [19]. The combustion of natural gas in the burner was modelled using the combustion functions of the ANSYS - Fluent package. The properties of the material heated and the furnace structural materials were updated with the temperature changes during heating [17]. This ensures a significant improvement of accuracy in the temperature field determination.

The system of equations forming the mathematical model of the heating charge in the furnace was solved by the method of control volumes with second order upwind scheme of discretization. The Coupled algorithm was used for the description of the coupling of the pressure and velocity fields in the model during the calculations. The controlled level of residues was at the level of at least 10-3 for momentum and continuity and 10-6 for energy and DO - intensity.

3. Experimental investigation

Models describing heat transfer in the chamber furnaces typically assume that radiation is the prevailing mechanism of heat transfer, and convection is neglected without modelling the combustion gases flow through the heating furnace chamber. Neglecting this mechanism in the zones where burners operate may lead to an incorrect simulations of the temperature field [16]. At the first stage of the investigations, an experiment of the charge heating at the laboratory chamber furnace operated by the Department of Thermal Engineering and Environment Protection of AGH University in Krakow was carried out. The charge temperature at 3 points and the temperature of refractory lining and insulation at 3 points were recorded. A scheme of the furnace is shown in Fig. 1. The furnace length was 1800 mm, height 1000 mm and width 900 mm, and it was equipped with one burner. The thickness of the insulating layer was 220 mm. The charge dimensions were: diameter of 80 mm and length of 337 mm. Temperature measurement was carried out continuously at a sampling rate of 10 Hz, with type K thermocouples.

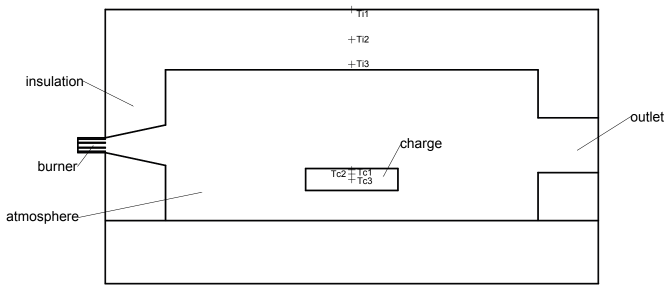

Fig. 1. Scheme of the research station (Ti - point temperature measurement of insulation, Tc - temperature measurement charge point)

The measurement also included recording of natural gas consumption and a combustion gases analysis, which was the basis for determining the combustion gases volume. Measurement of the volume flow of the gas supplied to the burner was made using a rotameter. An analysis of the exhaust flue duct was made using a gas analyser, the PG 250 Portable Multi-Gas Analyser. The results of the analysis were used to determine the amount of combustion air (Table 1.).

TABLE 1

Chemical composition of combustion gases

	Unit	32 min	65 min
CO_2	%	10.02	9.34
O_2	%	1.54	1.35
C_xH_y	%	0.04	0,03
NO_2	ppm	1	0
NO	ppm	54	59
CO	ppm	26	98
N_2	%	88.4	89.28
λ	-	1.07	1.06

4. Numerical computations and results of the laboratory furnace

The results of numerical calculations were compared with the measurement results. Numerical calculations were performed and the steel charge heating process was analysed.

The heating time to the temperature of 1000°C in the charge axis was about 65 minutes. The calculations have been started from the cold charge placed into the furnace. The computing results were used to validate the developed heat transfer model implemented in an ANSYS - Fluent environment. In the case of the numerical model, after 65 minutes the temperature achieved in the middle of the charge is 1012°C, and so the difference in relation to the experimental data is below 2%. Figure 2 shows the geometry and the numerical mesh applied in the calculations.

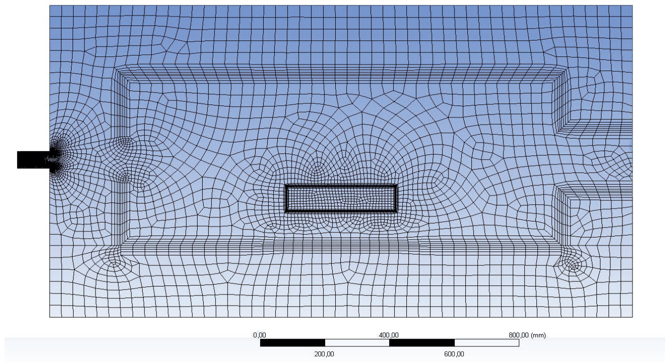

Fig. 2. The geometry and the numerical mesh applied in the laboratory furnace model

The calculation results yield the temperature fields in the charge and in the laboratory furnace walls. The temperature and velocity fields have been presented for a half of the heating time at the 32nd minute (Fig. 3) and at the end of the heating process at the 65th minute (Fig. 4).

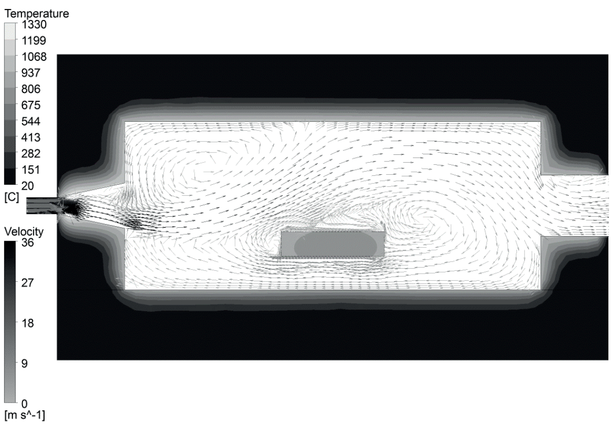

Fig. 3. The temperature and velocity field after 32 minutes of heating in the laboratory furnace

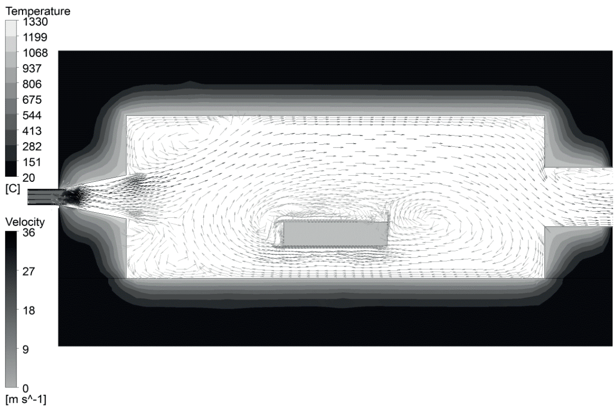

Fig. 4. The temperature and velocity field after 65 minutes of heating in the laboratory furnace

The temperature and velocity fields are typical for heating processes in chamber furnaces. Heat transfer conditions differ essentially in the furnace chamber. In the zone were burners are installed, there is an intensive convective heat transfer between hot gases resulting from natural gas burning and the surface of the walls and the charge. However, in other zones combustion gases move much faster. The calculation results presented in Fig. 5 and Fig. 6 show an agreement of calculation results and temperature measurements at the test rig.

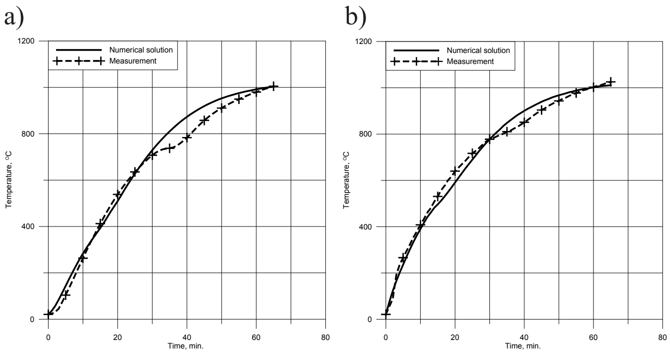

Fig. 5. Comparison of the numerical calculations of the charge temperature with measurements at the test strand a - at the charge axis, b - at the charge surface

The major differences of the temperature curves at the charge axis may result from neglecting the heat of phase transformation in the formulated model.

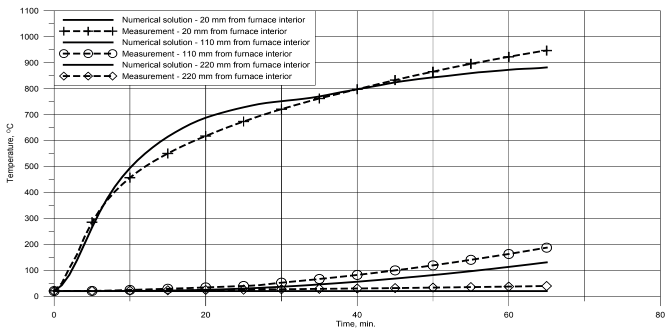

Fig. 6. Comparison of the numerical calculations of the furnace temperature with measurements at the test station

The temperature field in the charge cross-section after heating is presented in Fig. 7. A typical isotherm distribution for heating in a chamber furnace can be seen. At the end of heating time the temperature at the charge centre obtained from the measurement was 1003 °C, and from the calculations was 1010 °C. At the same time, at the surface a temperature of 1019 °C and 1012 °C from measurements and calculations have been obtained, respectively. The highest temperature was measured at the top corner at the burner side and it was about 1042 °C.

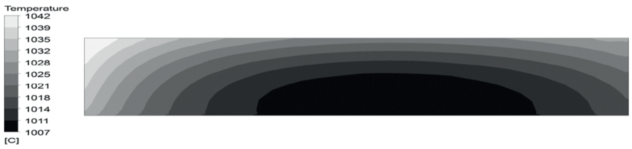

Fig. 7. The charge temperature field heated in the laboratory furnace after 65 minutes

5. Numerical computations and results for industrial chamber furnace

Two geometries of chamber furnace were created for the same model settings, with burners installed at the side wall and at the chamber roof. The heating process of the charge in the form of 2 cylinders with a diameter of 800 mm and length of 6000 mm was analysed. The cylinders were placed next to one another at the furnace bottom using spacers (not shown in the picture), which ensure a uniform combustion gases flow around the charge. 10 hours heating time was taken in both cases. A 20 °C initial temperature of both the charge and the furnace has been assumed. The dimensions of the furnace chamber were: width – 3200 mm, height – 3000 mm and length – 8000 mm. The simple burner geometry was the same in both cases.

The authors had no measurement data in the case of industrial furnaces so the mesh sensitivity analysis was performed on the mean temperature of the charge 1 and 2 (left and right side). The analysis started from the mesh numbering of 2460 volumes and it gradually concentrated until the average temperature of the charge did not change. The results are shown in Figure 8. The average values of temperature are presented in the form of a dimensionless ratio of the largest number of numerical mesh (12788 items) to individual meshes. As can be seen from the Figure 8 graph, for the mesh with 4465 volumes the differential average surface temperature of the charge 1 is less than 2% compared to the result obtained for the mesh with 12788 volumes. It was therefore considered that the mesh number of 4465 is sufficient for obtaining correct results. The accuracy of mass and energy balance was less than 1%.

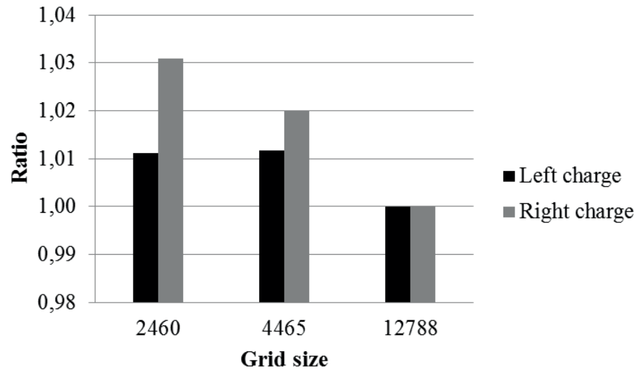

Fig. 8. Influence of mesh size on the calculation results

The temperature field of the charge and the furnace (Figs. 9 and 10) shows the influence of the location of the burners. The change in the burner locations makes a significant difference in the heating of the charge located in the furnace chamber. Placing the burners at the furnace roof without changing the exhaust gases' escape hole position results in a considerably higher temperature within the chamber. It involves a change in the heating conditions of the charge resting on the furnace bottom. The comparison of temperature distributions at the charge axes for chamber type I and II is presented in Fig. 11. The temperature increase rate varies depending on the burner locations and the position of the charge at the furnace bottom.

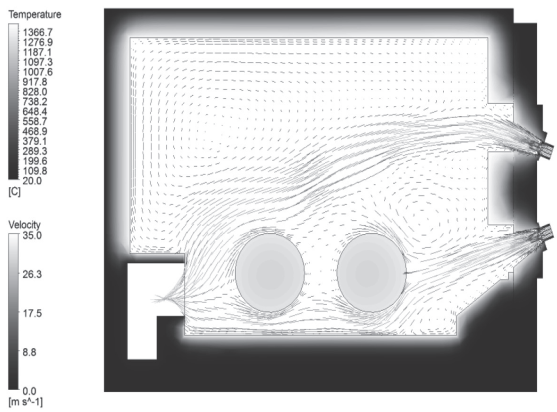

Fig. 9. The temperature and velocity fields for chamber furnace I after 10 hours

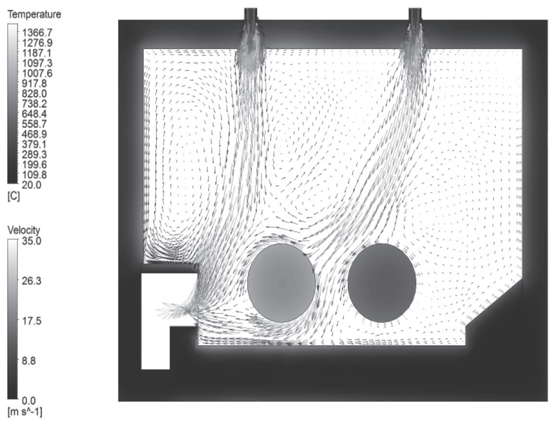

Fig. 10. The temperature and velocity fields for chamber furnace II after 10 hours

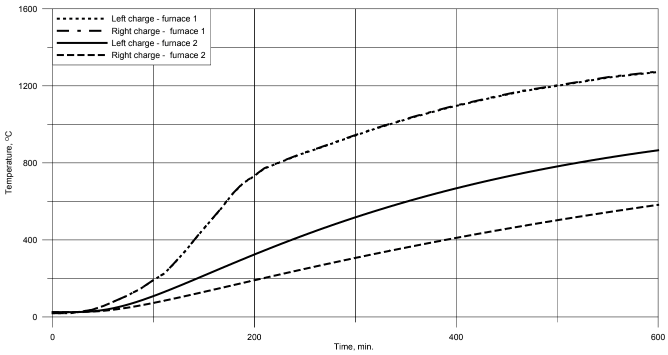

Fig. 11. The comparison of temperatures variations at the charge axis heated in chamber type I and II

For burners mounted at the furnace roof it is necessary to change the layout and system of exhaust gases flow from the furnace chamber. Modifications should aim at a uniform discharge of gases flow from the chamber at two sides of the furnace. This should ensure that the differences in the charge temperature depending on its location decrease.

6. Conclusion

The two dimensional model of the chamber furnace with various locations of gas burners have been developed using the ANSYS - Fluent 14.5 package. The effect of burner locations in the chamber furnace on the temperature field of the charge for plastic forming processes have been analysed. In order to verify the model assumptions, a model of the laboratory chamber furnace has first been constructed. The numerical results have been compared with the measurements. It follows from the analysis that a change in the burner positions in the furnace has a significant effect on the temperature field of the charge. A change in the burner position should be accompanied by a change in the combustion gases' discharge system. It should allow a uniform flow of the hot exhaust gases over the charge surface. A further stage of research will be focused on the development of a three dimensional model to facilitate more accurate numerical calculations. The model verification will be performed based on measurements conducted at an existing industrial chamber furnace for the charge heating prior to the forging process.

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