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MODIFICATION OF CHARGE HEATING TECHNOLOGY IN INDUSTRIAL FURNACES DURING RAILS PRODUCTION

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Abstract

The paper contains the methodology of the heating routines modification during the production of rails. The modification was aimed at the improving of final product quality combined with the decrease of the energy consumption and keeping the productivity unchanged. The scientific work resulted in the elaborating of new heating routines for walking beam furnaces set at lower temperatures. It was successfully applied in one of the polish steel plants and brought measurable economical benefits.

Key words: rolling of rails, charge heating, mathematical modeling

1. INTRODUCTION

Hot metal forming is carried out at high temperature, which, depending on technology of the process generally belongs to a range of 800–1300°C. The level of temperature is achieved by heating the material in high temperature devices, mostly industrial furnaces. During rolling processes heating is provided by pusher and walking beam furnaces which are supplied with the natural gas. The dimensions of the furnaces depend on numerous factors and usually varies between a few and tens meters. In the furnace chamber three zones can be usually distinguished. First charge is preheated mainly in convection manner by flue gases passing above the billet surface. There are no burners present in this zone. Subsequently billets shift to the second zone, usually called heating zone. Charge is heated by radiation and high temperature is achieved by combustion carried out in numerous gas burners. The same mechanism of heat transfer occurs in the third, equalizing zone, where temperature equalization in the charge volume takes place. The heat inside the metal propagates by conduction. Diversity of the partial physical phenomena characteristic for high temperature industrial furnaces makes difficult a full mathematical description of the heating process. This problem is widely discussed in a scientific literature, for instance [2,3,5,6].

The level of charge temperature, when released from the furnace chamber, is determined by the final temperature after rolling. When rolling the billet surfaces lose heat to the surroundings by radiation and convection and also to the rollers at the spots of a direct contact. From this point of view it is advisable to heat the billets to highest acceptable temperature. On the other hand high temperatures in furnace chamber result in the high gas consumption, metal loses owing to steel surface oxidation. Also the soft skin process can occur, which strongly influences

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the surface grade. Therefore the heating routine of the charge in furnace plays a key role in the whole technological process and decides about the final product quality.

2. VERIFICATION METHOD

For various reasons two walking beam furnaces are used to heat the charge in the analyzed technology of rails production. First, ambient temperature billets are brought up to a temperature of approx. 1280°C in a three zone furnace (furnace No1). Next they are preliminarily rolled in a two–high reversing mill and shifted to a second two zone furnace (furnace No2) to alter temperature drop induced by rolling. Subsequently they are delivered to the final rolling mill.

The analysis of the production technology regarding to lower furnace temperature has been carried out using the heat transfer calculations during rolling and heating. The heat loses from the metal surface to surroundings were determined including heat of plastic deformation and phase transitions. Basing on those calculations final temperature of rails has been computed. This way the minimal temperature of the charge released from the second furnace was found. In parallel rolling torque and power were also assigned to verify the possibility of correct mill operation. Similar technique has been adopted for the release temperature determination in furnace No1. The temperature drop during preliminary rolling has been calculated to find required temperature of heated charge. Then new heating routines in both furnaces have been elaborated which fulfilled proper rolling demands. The mathematical and numerical models of the heat transfer at every stage of the rolling processes have been developed.

3. HEAT TRANSFER MODEL

Solution of Fourier–Kirchhoff equation let calculate temperature distribution inside billets.

$$\frac{\partial t}{\partial \tau} = a\nabla^2 t + \frac{\dot{q}_v}{\rho c_p} \tag{1}$$

where ∇^2 – Laplace operator, a – steel thermal diffusivity, ρ – steel density, c – steel heat capacity, $\dot{q}_v$ – density of heat sources including plastic deformation and phase transition, τ – time.

The temperature–dependent thermal properties of steel has been assumed in the model. The boundary conditions of heat transfer equation has been established separately for every stage of rails production, i.e. heating in a furnace and cooling during rolling. The simplified parametric heat transfer model has been developed for the furnace chamber. The heat flux density at the billet surface has been evaluated from a general relation:

$$q_i(x_1,x_2,x_3)=\alpha_i(x_1,x_2,x_3)[t_{wi}(x_1,x_2,x_3)-t_{ai}(x_1,x_2,x_3)] \in S_{wi} \tag{2}$$

where q – heat flux density, α – heat transfer coefficient between billet and surroundings, t – temperature, x_1, x_2, x_3 – space coordinates, S – area of the surface enclosing billets. Subscript w is related to the billet surface, subscript a is related to the enclosure surface, subscript i defines number of enclosing surface (furnace walls, roof, etc).

Heat transfer coefficients between surroundings and billets surfaces can be estimated from the Stefan–Boltzmann equation taking into account convection factor

$$\alpha_i = C_i\,\varepsilon_{zi}\,5{,}675\cdot 10^{-8}\,\frac{(t_{wi}+273)^4-(t_{ai}+273)^4}{t_{wi}-t_{ai}} + \frac{Nu\cdot\lambda}{l} \tag{3}$$

Surface temperature of furnace side walls, t_{a1}, t_{a2}, charging and discharge doors t_{a3}, t_{a4}, furnace roof and bottom t_{a5}, t_{a6} can be individually introduced to the model basing on the experimental data. Symbol λ means thermal conductivity of passing flue gases, l – linear dimension, Nu – the Nusselt number. The emissivity of the billet surfaces mentioned above and flue gases have been calculated from the empirical relations [4]. The thermal properties of steel were approximated regarding their variation with temperature. To adjust the model to the results of experimental temperature measurements of furnace atmosphere and in selected internal points of the billets parameters C_i were properly selected. The calculation begins at the moment, when a billet is charged into the furnace.

The Fourier–Kirchhoff equation has been discretized using **F**inite **E**lement **M**ethod **FEM**. The residual weighted method applied to the heat conduction equation leads to the linear system of equation when linear temperature variation in the time increment is assumed. The solution of the system lets calculate the temperature distribution inside a steel billet. The detailed description of the method can be found in numerous papers [1,4,7].

The heat transfer during rolling has been described by the specific boundary conditions using the conduction model in a billet unchanged. It has been assumed that the heat loses from billet surfaces proceed by radiation and convection. Likewise the heating process in furnace equation (3) has been used. The effect of the billets' surface water cooling on the heat transfer has been also considered. The specific mathematical relations applied in calculations has been drawn from literature or self made experiments [4]. This way the heat fluxes during rolling, water cooling, heat generation caused by plastic deformation, and radial properties of the steel have been computed.

4. EXPERIMENTAL VALIDATION OF THE MODEL

Boundary conditions of the heat conduction equation must be precisely defined and known to obtain the proper solution of the mathematical problem. Exactness of boundary conditions estimation strongly impacts on the numerical calculations results. Sometimes the separate mathematical models are developed to find the heat transfer coefficient or heat flux at the billet surface. The only way to verify them is the experiment carried out under industrial circumstances. The most important and possible to measure parameter of the heated charge is its temperature. Results of temperature measurements at various position inside the billet compared to the results of numerical calculations allows the estimation of model correctness. Then the solution can be optimized regarding to the selected parameters of the model. Sometimes, for the simplicity, some parameters can be changed arbitrarily to find the best solution which is rewarding for the user. Subsequently such a validation allows to make simulations of the charge heating for various heating conditions or steel grades.

For the needs of validation the industrial experiment has been performed. The temperature of the heated and rolled billets has been measured and registered. At every stage of rolling surface temperature has been measured by thermovision infrared camera equipped with focal plan array uncooled microbolometer. The temperature has been recorded on–line. The slab has been observed by the camera at various position during rolling: when released from the walking beam furnace No1, after each pass in a two–high reversing mill, when charging to and discharging from a furnace No2, after each pass in a final rolling mill. The temperature measurements allowed to monitor slab temperature at the different stages of the rolling process.

Measurements of charge temperature during heating in walking beam furnaces proved to be much more difficult and complicated. Pyrometric methods could not be employed for the reason of measurement errors and the leak of possibility to monitor the charge temperature profiles throughout the furnace. Moreover such methods give the data regarded to surface temperature, while its differences inside the billets strongly effects on the quality of heating process. For the cold billets the expensive monitoring system mounted on a special "fork" welded to the billet can be used. The equipment travels with the product to monitor its temperature throughout the furnace. The main element of it is a box made of a rugged high grade stainless steel to resist high temperatures and cooled by water evaporation. Additionally it is insulated with insulant to protect the box from direct radiation. Inside the data logger is connected to several thermocouples mounted in the billets. The system travels with the charge and records the sensors indications. The separation of the system and the slab at the final stage of heating is the main problem and limits its application solely to the selected types of furnace discharge systems. It is also extremely difficult to mount the system on the hot billet, what sometimes occurs in industrial experiments. Moreover the measuring box changes the heat transfer between slab surface and surroundings and reduces the measurements accuracy, especially for the small geometrical dimensions of the heated billet. In the presented work another measurement system has been employed. It consisted of several self made K type thermocouples 2 mm in diameter and of a approximately 5 m longer then a furnace chamber, i.e. about 27 m and 21 m for the furnace No1 and No2 respectively. Beforehand characteristic curves of thermocouples have been made at a laboratory stand.

The thermocouples were placed in selected points inside the test billet. Additionally one thermocouple measured the temperature just above the billet surface. For the industrial trial the billet of 280×400×5600 mm in size have been prepared. The sensors were mounted before charging in the chamber and moved with the billet up to the heating end. The schema of the sensors displacement is shown in figure 1.

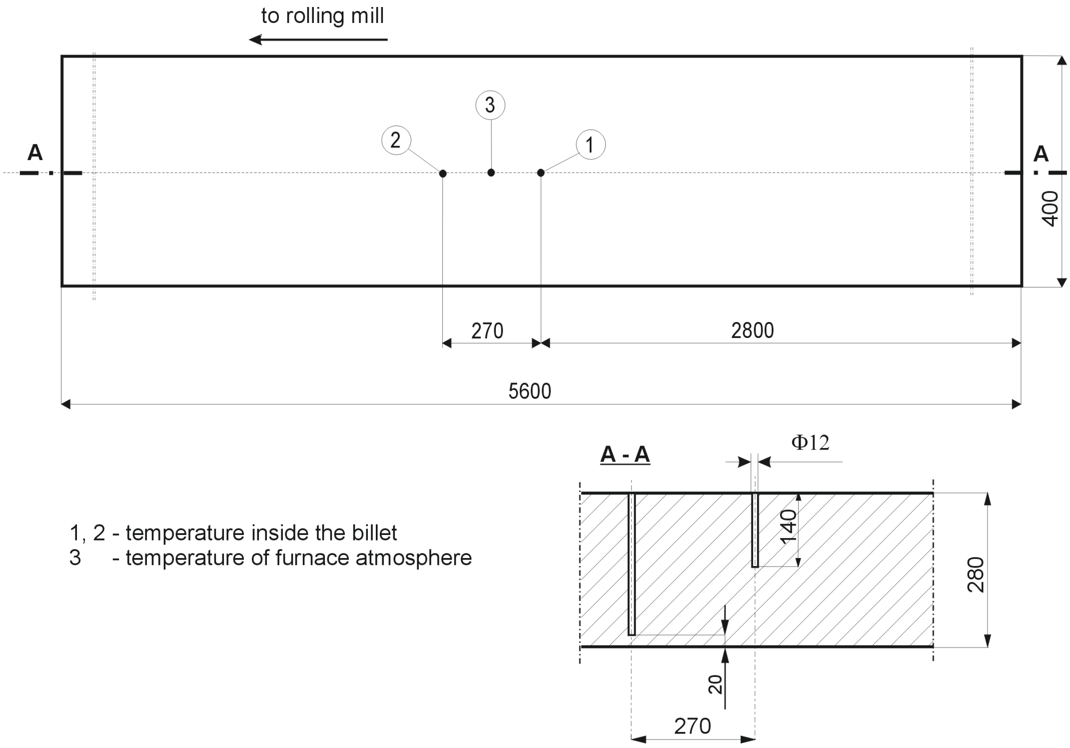

Fig. 1. Temperature measurement points for billets heating in the walking beam furnace No 1.

In the same manner an industrial test has been carried out for the second walking beam furnace. A steel billet of 280×262×4900 mm in size has been prepared. The billet was preheated in the first furnace. The rolling in two–high reversing mill was omitted. After that the billet has been equipped with three long enough thermocouples and immediately charged into the second walking beam furnace. The high accuracy data acquisition system has recorded the measurement results continuously. The sensors traveled over the furnace chamber and were released with the heated slab.

The maximum temperature achieved in the first furnace preheating the charge from ambient temperature do not exceed 1300°C, while in the second furnace it was equal to approximately 1220°C. The length of the chambers for the walking beam furnaces No1 and No2 is equal to 22 m and 16 m, respectively.

5. VALIDATION RESULTS AND ANALYSIS

The calculation of the temperature profiles for both tests have been performed. The identification of a selected parameters of mathematical model has been carried out to achieve the best accordance between industrial trials and simulation results. The results of measurements and computations are shown in figures 2, 3 and 4. The discrepancy in temperature profiles do not exceed 50 K except surface temperature. Measurements of this temperature are not precise for its variation with scale forming at the slab surface (figure 2), so temperature monitoring in some internal points of a slab volume is necessary. Considering the extremely tough technical circumstances of the trials, possible errors of temperature measurement and finally the goal of the work the similarity of temperatures profiles seem to be good enough.

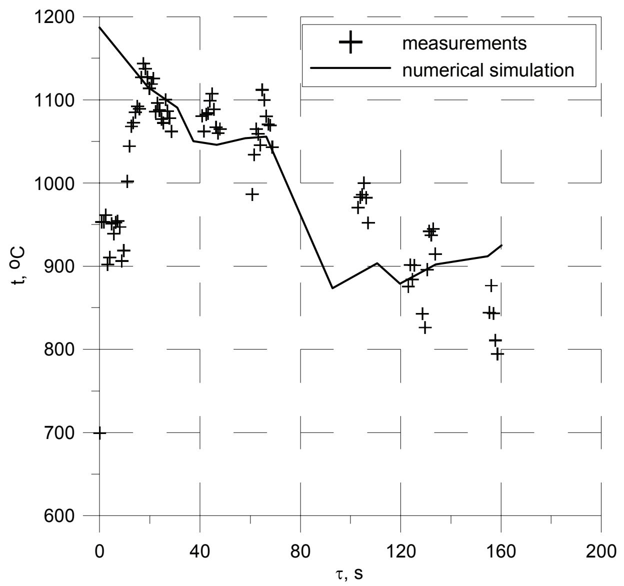

Fig. 2. The comparison of the measured and calculated maximum temperature at the slab top surface after each pass in reverse rolling mill.

The sufficient accuracy was also observed for the temperature profiles measured and computed in selected internal points of the slab moving over the both walking beam furnaces. The results confirmed the correctness of the developed models and make it possible to apply them for numerical simulations of the rail rolling process. Therefore new technologies can be elaborated without expensive and time consuming industrial tests.

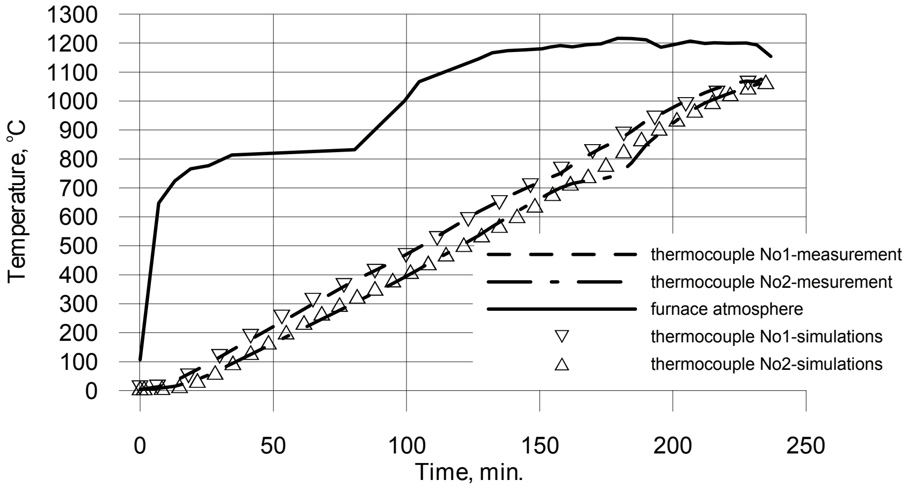

Fig. 3. Results of measurements and computations for the walking beam furnace No1.

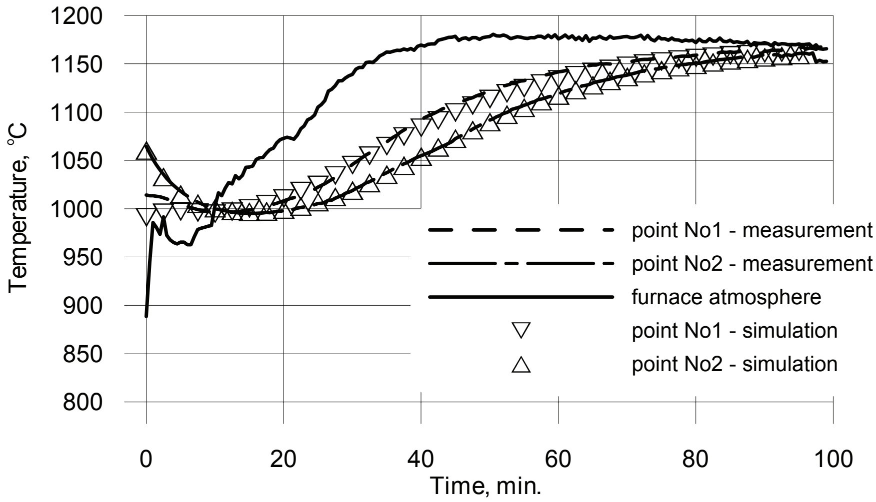

Fig. 4. Results of measurements and computations for the walking beam furnace No2.

6. THE CORRECTIONS OF SLAB HEATING

The numerical simulations of the rail rolling processes hale been executed using the developed computer programs for various heating routines in both walking beam furnaces. The computations included several temperature setting in furnace zones. The temperature has been lowered regarded to original values. The results showed that the corrected heating routines guaranteed temperature profiles at the discharge moment good enough to ensure proper quality of the final product. The thickness of the decarburizated and oxidized layers have been significantly decreased. This lead to the elaboration of the new heating routines based on the reduced temperature setting of the control thermocouples in furnace chambers.

The temperature reduction in the walking beam furnace No1 was about 10–30 K in the preheating zone and about 50–60 K in the rest of the furnace chamber. For the furnace No2 the reduction has been set approx. 20 K less than before. The new technologies have been proposed for all types of steel rolled in the steel plant. The test trials in industrial circumstances have been performed during 5 weeks of operation. The corrected heating technologies resulted in the gas consumption reduction related to a mass unity of the rail production. The decrease of this parameter was about 3.0 m^3/Mg for the furnace No1, and approx. 2.2 m^3/Mg for the furnace No2. Considering total mass production during trial period the gas savings were estimated at about 54000 m^3. It should be resolutely underlined, the total output of the whole rolling mill has been supported. The final products met also all the quality requirements.

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MODYFIKACJA TECHNOLOGII NAGRZEWANIA WSADU W PIECACH GRZEWCZYCH W PROCESIE PRODUKCJI SZYN

Streszczenie

W artykule opisano metodologię modyfikacji programów nagrzewania wsadu w procesie produkcji szyn. Modyfikacja miała na celu poprawienie jakości produktu końcowego połączonego z obniżeniem jednostkowego zużycia energii przy zachowaniu niezmienionej wydajności. Prace badawcze pozwoliły na opracowanie nowych programów nagrzewania w piecach pokrocznych charakteryzujących się niższymi temperaturami w kolejnych strefach pieca. Wyniki zostały wdrożone w jednej z polskich hut stali przynosząc wymierne korzyści ekonomiczne.

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