ISSN 0543-5846
METABK 46 (4) 291-293 (2007)
UDC - UDK 621.783.233–97:662.614=111

OPERATION INDICATORS OF THE ROTATING-HEARTH FURNACE IN RESTRICTIVE MANUFACTURING CONDITIONS

Received - Primljeno: 2006-07-26
Accepted - Prihvaćeno: 2007-01-20
Professional Paper - Strukovni rad

The heating operation of the rotating-hearth furnace involving semi-finished steel products was analysed, and specific heat consumption was determined as a function of furnace productivity. The aim was to find out how a change in productivity, which is not accompanied by a modification of the thermal regime, can affect the heating quality and surface oxidation of products.

Key words: *rotating-hearth furnace, thermal regime, heat consumption*

Pokazatelji rada kružne peći u restriktivnim uvjetima proizvodnje. Analizirana je provedba zagrijavanja čeličnih poluproizvoda u kružnoj peći i određena je specifična potrošnja topline u ovisnosti o proizvodnosti peći. Istražen je utjecaj promjene proizvodnosti kružne peći pri nepromijenjenom toplinskom režimu na kvalitetu zagrijavanja čeličnih poluproizvoda i na oksidaciju njihove površine.

Ključne riječi: *kružna peć, toplinski režim, potrošnja topline*

INTRODUCTION

For the manufacture of seamless steel tubes by forging in a pilger mill a charge having a circular or polygonal cross-section is used after it has been preheated in a rotating-hearth furnace. The furnace resembles a closed circular tunnel consisting of a ring-shaped bottom, side walls (outer and inner), and a roof. Charging and discharging take place through the door in the outer wall. The ring-shaped bottom, provided from beneath with two concentric rails, rests on metallic rollers which are fastened to a concrete base. The charge is heated with pieces lying apart on the bottom, in rows of two, one and a half, or one. The bottom has a mean diameter of 14 m, a working width of 3,62 m, and a total surface of 159 m^2, it is rotated by an electric motor, and revolutions are transmitted by means of a cogwheel onto an annular sawtoothed rack affixed to the centre of the bottom from below. The sealing of the revolving bottom and the fixed section of the tunnel (side walls) is accomplished with the help of the rings fastened to the outside and inside of the revolving bottom, which are made to fit to the water troughs in the side walls of the furnace. The charge is passed through three thermal zones: the preheating zone, the heating zone and the soaking zone. There are 13 burners in the first zone, another 13 in the second and 8 burners in the third. The burners are positioned on the outer and inner wall portions of the furnace. The furnace is natural gas fired, with a heating value of about 35900 kJ/m^3. Preheating the combustion air to a temperature of 400 °C is accomplished in a recuperator. The temperature, pressure and gas/air ratio are controlled automaticaly by regulators which are adjusted to the furnace operation and have two basic functions: to measure zonal temperature and to signal to the servomotor to open up or close down the natural gas or air supply valves (ratio control) in order to maintain the temperature regime in the furnace [1].

J. Črnko, P. Jelić, L. Lazić, M. Kundak, Faculty of Metallurgy University of Zagreb, Sisak, Croatia

HEAT CONSUMPTION DURING CHARGE HEATING

To get a realistic picture of how specific heat consumption (q) relates to furnace productivity (p) operation of the rotating-hearth furnace in the Sisak Tube Rolling Mill in Croatia, was followed and analysed over the period from 2004 to 2006. Only the pairs of data (q_i, p_i) relating to the heating of a steel charge of DIN St 45.4 quality having a twelve-angled cross-section, the diameter of the inscribed circle of 428 mm, and a length of 1350 mm, were used for analysis by the regression method. In the 10-15 t/h productivity region the empirical regression was defined by the following equation:

$$q = 2903 - 98{,}03 \cdot p + 2{,}20 \cdot p^2, \quad /(\mathrm{MJ/t}) \qquad (1)$$

(correlation coefficient r = 0.9515).

Figure 1. shows a regression curve drawn in accordance with equation (1), and all statistically relevant points. The productivity at minimal specific heat consumption was 22,35 t/h.

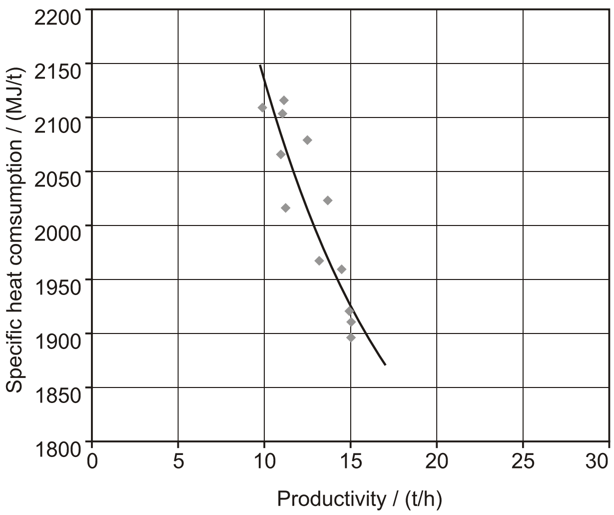

Figure 1. **Dependence of specific heat consumption on furnace productivity**

Slika 1. **Ovisnost specifične potrošnje topline od proizvodnosti peći**

Estimate of operational data concerning natural gas consumption which is based on the amount of heat required with respect to the heating value of the fuel usually includes the data for "blind" fuelling. Variation in heat losses demonstrated by the heat balance over the period of observation could be accounted for by altered operational or engineering conditions. Variable operation of the rotating-hearth furnace was due to frequent delays caused by damaged rolling plant equipment, drop in productivity, or a halt in the rolling mill operation either because of lack of charge or for failure of demand.

Diminished productivity of the rotating-hearth furnace which is not accompanied by a change in the thermal regime is bound to bring about an increase in the surface temperature of the charge. As a result, steel scaling will increase as will be specific heat consumption. Steel scaling in rotating-hearth furnaces is reported to be of lesser extent than in other types of furnace, and comes to 0,5-1 per cent [2]. Data for pusher furnaces operating in the Sisak Ironworks show the scaling percentage to be 0,6 [3, 4], so that the figures reported under [2] need not be taken as generally valid.

Surface oxidation of the heated semi-finished steel product is a process which begins and practically ends at high temperatures. As much as 70-80 per cent of the scale is formed over a high temperature range (1000-1300 °C). At high temperatures all the three basic iron oxides are thermodynamically stable. The scale formed in such conditions is composed of wüstite (FeO), magnetite (Fe_3O_4) and hematite (Fe_2O_3). The final thickness of the scale layer is defined by the laws valid for that temperature and scale structure. Figure 2. is a photomicrograph of a cross-section of the scale layer formed on a semi-finished steel product of St 45.4 quality, at furnace productivities of 15 and 13,5 t/h, and at constant thermal regime.

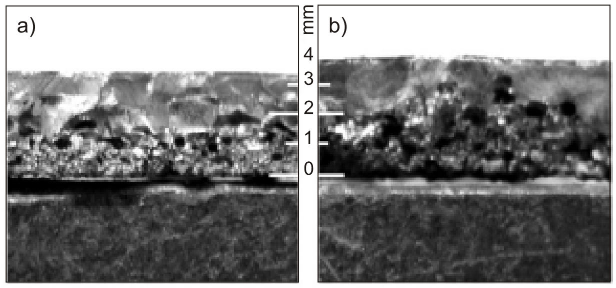

Figure 2. **Photomicrograph of scale cross-section: a) at 15 t/h productivity; b) at 13,5 t/h productivity**

Slika 2. **Fotografija poprečnog presjeka ogorine: a) pri proizvodnosti 15 t/h; b) pri proizvodnosti 13,5 t/h**

Increase in steel temperature above a certain limit will cause melting. The final outcome of overheating of the rotating-hearth furnace, therefore, will be steel loss, scale-induced rising of the bottom level, and elevated specific heat consumption.

FURNACE PRODUCTIVITY AND LOADING OF THE RING-SHAPED BOTTOM

In the rotating-hearth furnace where semi-finished products are offset from one another the product surface exposed to heat transfer in larger than in the case of close drawn load pieces in pusher-type furnaces. Heat absorption by radiation will depend on the magnitude of the angle opening towards the radiation-accessible sections of the product. However, heat absorption by vertical surfaces is almost always limited by the shading effect of the neighbouring products which diminish the free-space angle as they seldom lie on the bottom more than 1d apart (where d is the product thickness or its diameter). The heat also gets absorbed through the bottom sections which are not occupied by the charge pieces as well as by convection. Heating control in the rotating-hearth furnace therefore makes it possible to choose between higher heating quality and larger bottom load, and this in tum, makes it possible to control the effect of surface heating. In other words, the limit bottom loading value can be determined as a function of heating quality.

For want of funds for the purchase of charge on the world market the rotating-hearth furnace in the Sisak Tube Rolling Mill has been operating outside the customary standards and rolling mill practice [5]. According to the norms, polygonal steel charge pieces, the diameter of the inscribed circle of 428 mm, are to be deposited on the ring-shaped bottom following two possible arrangements depending on the expected productivity rate. One arrangement anticipates loading 54 semi-finished products against the outer section of the ring-shaped bottom and 42 products against the inner bottom section (nominal furnace capacity). According to the second arrangement 48 semi-finished products are loaded around the centre of the ring-shaped bottom (restrictive furnace capacity). With either arrangement the distance between the products is 428 mm. At constant thermal regime a change in the parameters dependent on the type of arrangement, for instance the ratio of the heated surface of the product and the inner heating surface of the furnace (Ψ), will bring about a change in the heating rate. For the first arrangement $\Psi = 0{,}395$, for the second $\Psi = 0{,}195$. The change in the heating rate will induce a change in furnace productivity. The productivity will be further affected by indirect effects of other parameters which are not dependent on the type of arrangement, e.g. by the length of the product. However, when the load of the ring-shaped bottom falls below the value that is in accordance with the established thermal regime, the heating time that has been valid until that moment will become too long, will induce a higher surface temperature and, accordingly, a higher loss due to enhanced surface oxidation of semi-finished steel products. Details of the thermal regime measured with an optical pyrometer (Optix, Keller) in the rotating-hearth furnace in the Sisak Tube Rolling Mill are shown in Table 1. at the furnace productivity of 15 t/h, and in Table 2. at the furnace productivity of 13,5 t/h.

Table 1. **Temperature regime of rotating-hearth furnace at 15 t/h productivity**
Tablica 1. **Temperaturni režim kružne peći pri proizvodnosti 15 t/h**

Measurement point	Distance from loading line / m	Temperature	
		wall facing door / °C	upper surface of semi-product / °C
Preheating zone	9,22	850	x
Heating zone	22,72	1190	1050
Heating zone	28,10	1260	1210
Zone dividing area	31,40	1270	1240
Soaking zone	36,96	1280	1270
x - below measurement area			

Table 2. **Temperature regime of rotating-hearth furnace at 13,5 t/h productivity**
Tablica 2. **Temperaturni režim kružne peći pri proizvodnosti 13,5 t/h**

Measurement point	Distance from loading line / m	Temperature	
		wall facing door / °C	upper surface of semi-product / °C
Preheating zone	3,79	1020	935
Heating zone	20,53	1180	1140
Heating zone	22,72	1245	1205
Zone dividing area	31,40	1270	1260
Soaking zone	36,96	1275	1265

Comparison of temperatures by zones shows the temperatures in the preheating and heating zones to be considerably higher at 13,5 t/h productivity than at 15 t/h productivity. This can be taken to account for higher surface oxidation of semi-finished steel products at 13,5 t/h productivity. It follows that a well set thermal regime helps reduce not only specific heat consumption but also the loss of material caused by surface oxidation of the heated semi-finished steel products.

CONCLUSION

Heat consumption is a part of overall energy consumption required for the manufacture of seamless steel tubes involving forging in a pilger mill. This type of production also assumes consumption of electric energy. In this work we examined the consumption of thermal energy required for the heating, in a rotating-hearth furnace, of a steel charge to be used for cup manufacturing. The formed cups are reheated in a reheating furnace, extended into tube blanks by means of an elongator, and rolled into tubes in a pilger mill. The inconsistencies and shortcomings concerning the present technological line in the Sisak Rolling Mill have been pointed out [6]. It must be added that in comparison with currently available up-to-date rolling technology the equipment for seamless steel tube rolling presently in use in the Sisak Rolling Mill has been largely outdated and falling far behind especially as concerns the charge yield. The restrictive operational conditions which have been imposed by charge deficiency or by failure of demand call for coordination of all technological parameters, or at least of the major ones. We have found out that diminished productivity of the rotating-hearth furnace, if not accompanied by a change in the thermal regime, will bring about a rise in the surface temperature of the heated product, which in turn will increase surface oxidation and cause further loss of steel through scaling.

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