HEAT LOSSES OF BLOOM IN THE HOT ROLLING PROCESS

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Abstract

The temperature of the bloom during hot rolling is a crucial factor for the quality of the final product. Heat losses during hot rolling which affect bloom temperatures were therefore experimentally investigated. Experiments were designed to simulate heat transfer on the bloom surface during rolling when: 1. the bloom does not move and is far from the work roll (heat transfer by radiation and free convection in air); 2. the bloom moves far from the work roll (heat transfer by radiation and forced convection in air); 3. the bloom moves close to the work roll so the residual water from roll cooling falls on its surface (heat transfer by radiation and forced convection by residual spray from work roll cooling). Roll bite is excluded in this paper. Experiments were performed with an austenitic steel plate embedded with thermocouples. The plate was firstly heated up to 900 °C and then repeatedly moved by a computer controlled mechanism through a section which simulated the blooming line. Three different velocities of 1, 3, and 5 $m \cdot s^{-1}$ were tested to observe the influence of velocity on the heat losses. The temperatures gathered during the experiments are evaluated numerically by an inverse heat conduction task and analytically. The final results show that the highest heat loss is caused by radiation; its value is 171 $W \cdot m^{-2} \cdot K^{-1}$ for 1,100 °C. The heat loss due to residual water from work roll cooling is 80-88 $W \cdot m^{-2} \cdot K^{-1}$ and the heat loss by forced air is found to be from13-29 $W \cdot m^{-2} \cdot K^{-1}$.

Keywords: Hot rolling, heat loss, heat transfer coefficient

1. INTRODUCTION

The quality of hot rolling final products is greatly affected by cooling – cooling of work rolls and cooling after hot rolling on a run-out table. The cooling process after hot rolling on a run-out table is influenced by many parameters (water flow rate, surface temperature of steel, water temperature etc.), which even today cause many problems, such as poor cooling uniformity [1-4]. Improper work roll cooling can adversely affect the profile and shape of the rolled material. The issue of work roll cooling and their service life has been dealt with by the authors in [5-8]. The crucial factor for the quality of the final product is the temperature of the bloom during hot rolling. Experimental work was carried out to investigate heat losses of the bloom during hot rolling. As the bloom is exposed to more heat transfer types during hot rolling, the heat losses were determined separately for stationary dry bloom, for moving dry bloom and for moving bloom when water residual from roll cooling falls on the bloom surface. Heat transfer by radiation, free convection and forced convection to ambient air and to falling water were evaluated by the calculations based on the experimental data. Roll bite was not investigated.

2. EXPERIMENT

Hot rolling was simulated experimentally in laboratory conditions. An austenitic steel test plate (material 1.4828) with a thickness of 25 mm was embedded with six thermocouples. The measurement points were 0.7 mm under the cooled surface and were welded to the test plate. All surfaces of the plate were thermally insulated except the tested upper one. The test plate was put on a moving carriage that is part of the 8 m long laboratory test bench shown in **Figure 1**. The test bench enables linear movement and can be also rotated by up to 180°. The test plate was heated up to 900 °C with the tested surface down in the electric heater (**Figure 1**) before the experiment. When the temperature of the plate reached 900 °C and the temperature field inside the plate was homogeneous, the electric heater was removed and the plate was rotated so that its surface was facing up. At the beginning of the experiment, the test plate was dry and did not move, which simulated zone 1, where the bloom is dry and stationary. Then the plate moved linearly towards the cooling section, which simulated zone 2, where the bloom is dry and moving. Finally, the test plate moved repeatedly backwards and forwards through the cooling section, which simulated zone 3, where the bloom is exposed to falling residual water from roll cooling (see **Figure 2**). The thermocouples inside the test plate were connected to the data logger during the whole experiment. Temperature history and test plate position were recorded throughout the whole experiment and downloaded to the computer after the experiment. Experiments were performed for test plate velocities of 1, 3, and 5 m·s^{-1}. The downloaded data were used to evaluate the heat transfer coefficient by an inverse heat conduction task [9].

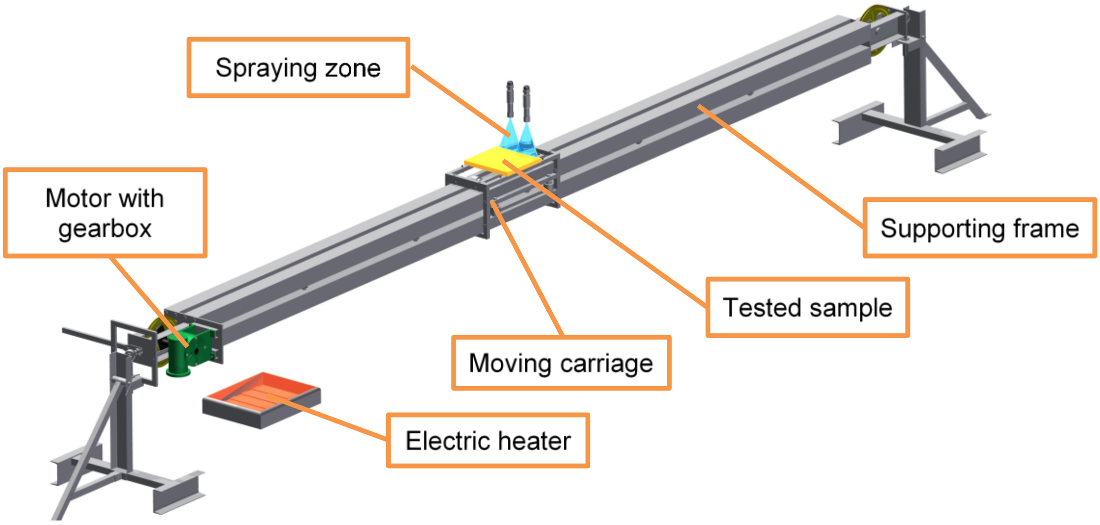

Figure 1 Experimental stand with moving tested sample

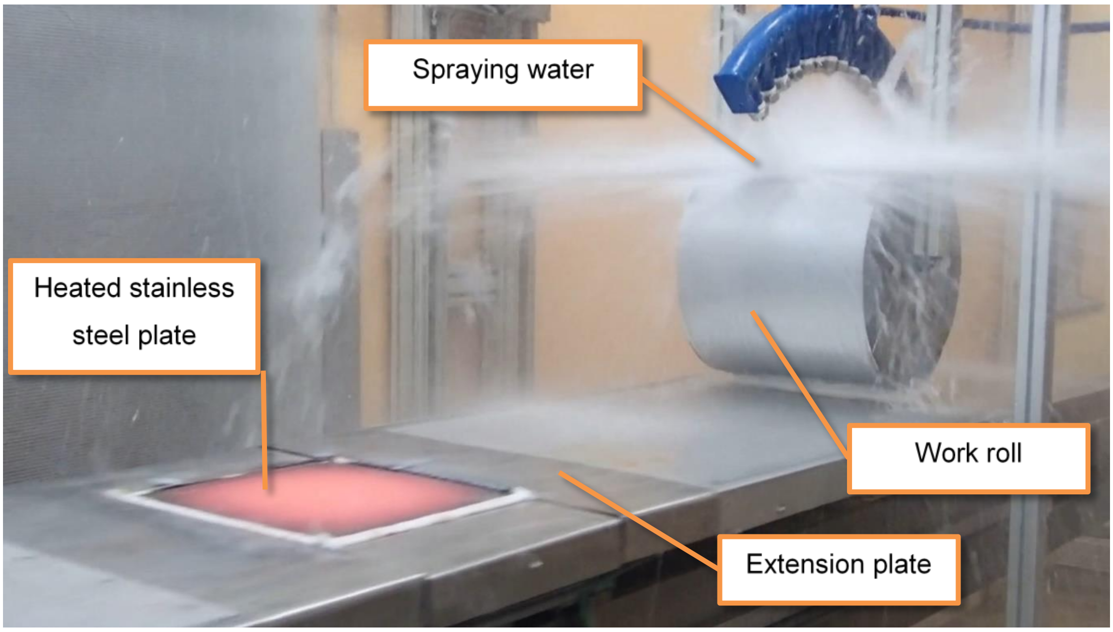

Figure 2 Photo of heat transfer measurement

3. RESULTS

3.1. Stationary dry bloom

Heat transfer on a stationary dry bloom surface (zone 1) is simulated at the beginning of the experiment that follows immediately after the test plate is pulled out from the electric heater. The test plate does not move and is dry. Heat from the stationary dry bloom surface is transferred to the air by free convection and radiation. The heat transfer coefficient determined for zone 1 by the inverse heat conduction task therefore consists of the heat transfer coefficients for free convection into the ambient air and for radiation:

$$h = h_c + h_r \tag{1}$$

where h is the overall heat transfer coefficient in zone 1 (W·m^{-2}·K^{-1}), h_c is the heat transfer coefficient for free convection into the ambient air (W·m^{-2}·K^{-1}) and h_r is the heat transfer coefficient for radiation (W·m^{-2}·K^{-1}).

The overall heat transfer coefficient was evaluated by the inverse heat conduction task from the experimental data. The heat transfer coefficient for free convection into the ambient air can be computed analytically [10]. The heat transfer coefficient for radiation is expressed by equation:

$$h_r = 5.67 \cdot 10^{-8} \varepsilon (T_s + T_{air})(T_s^2 + T_{air}^2) \tag{2}$$

where ε is the emissivity coefficient (-), T_s is the surface temperature of the test plate (K) and T_{air} is the ambient air temperature (K).

All quantities in equation (2) are known from the experimental work (see **Table 1**) except the emissivity coefficient. The emissivity coefficient can therefore be evaluated by the use of equation (1) and equation (2). The emissivity coefficient depends on the amount of oxides on the surface. The value of 0.84 was calculated for a surface almost free of scales (after the first heating in an inert atmosphere) and a value of 0.92 for the oxide surface. These values were also validated using pyrometer measurements. The surface roughness of the test plate free of scale was *Ra* = 3.2 μm and *Rz* = 56 μm in direction A (see samples in **Figure 3**) and *Ra* = 2.8 μm and *Rz* = 32 μm in a perpendicular direction B. The roughness of the test plate with an oxidized surface was *Ra* = 3.3 μm and *Rz* = 36 μm in one direction and *Ra* = 2.9 μm and *Rz* = 26 μm in a perpendicular direction.

Table 1 Heat transfer coefficients for stationary bloom for surface temperature of 870 °C and ambient air temperature of 20 °C

Oxidised surface	h (W·m^{-2}·K^{-1})	h_c (W·m^{-2}·K^{-1})	h_r (W·m^{-2}·K^{-1})
No	106	11	95
Yes	115	11	104

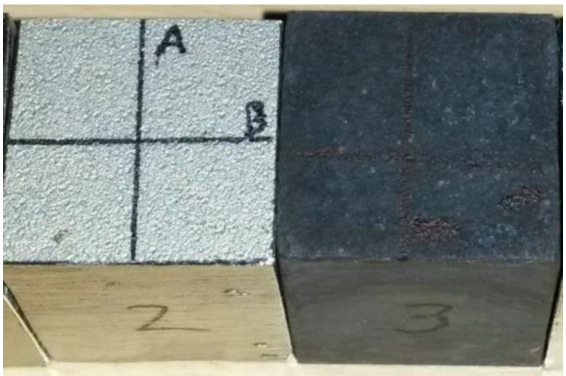

Figure 3 Samples for surface roughness measurements

3.2. Moving dry bloom

Heat transfer on the moving dry bloom surface (zone 2) is simulated by the heated test plate that moves at a speed of 1, 3 or 5 m·s^{-1} in the ambient air. Heat from the moving dry bloom surface is transferred by radiation and forced convection into the ambient air. The heat transfer coefficient determined for zone 2 therefore consists of the heat transfer coefficient for radiation and the heat transfer coefficient for forced convection into the ambient air. Equation (1) can be used, but h_c is now the heat transfer coefficient for forced convection into the ambient air (W·m^{-2}K^{-1}) and h is the overall heat transfer coefficient in zone 2 (W·m^{-2}K^{-1}).

The value of h_r was determined by equation (2) with emissivity coefficient ε valid for zone 1 for an oxidised surface. The value of h was evaluated by an inverse heat conduction task. The heat transfer coefficient for forced convection into the ambient air h_c can then be computed from equation (1). The values of h_c are summarized for a surface temperature of 800–900 °C in **Table 1** and are consistent with the results published by Laloui and Rotta Loria [11].

Table 2 Heat transfer coefficient for forced convection on the moving dry bloom surface (zone 2) and heat transfer coefficient for forced convection by the water on the moving bloom surface (zone 3), relation to surface velocity

Velocity (m·s^{-1})	**h_c *zone 2* (W·m^{-2}·K^{-1})**	**h_c *zone 3* (W·m^{-2}·K^{-1})**
1	13	88
3	19	83
5	29	80

3.3. Moving bloom hit by residual water from roll cooling

Heat transfer on the moving bloom surface (zone 3) is simulated by the heated test plate that repeatedly moves under the cooled roll at a speed of 1, 3 or 5 m·s^{-1} (see **Figure 1** and **Figure 2**). The amount of residual water from roll cooling was 1.9 l·s^{-1}·m^{2}. Heat from the moving test plate surface hit by residual water from roll cooling is transferred by the radiation and forced convection into the water. Equation (1) can also be used, but h_c is now the heat transfer coefficient due to the forced convection into the water (W·m^{-2}·K^{-1}) and h is the overall heat transfer coefficient in zone 3 (W·m^{-2}·K^{-1}).

The value of h_r was determined in zone 1, and h was evaluated by an inverse heat conduction task. The heat transfer coefficient for forced convection into the water h_c can then be computed from equation (1). The values of h_c are summarized in **Figure 4**. The position 0 mm is directly under the roll. The high peak in the centre is caused by water accumulated in the roll gap. The smaller peaks at positions of -500 mm and 500 mm are caused by water dropping from the cooled work roll. The values of h_c shown in **Figure 4** were averaged at a position interval of (-1,000; 1,000 mm) for each movement velocity and can be seen in **Table 2**.

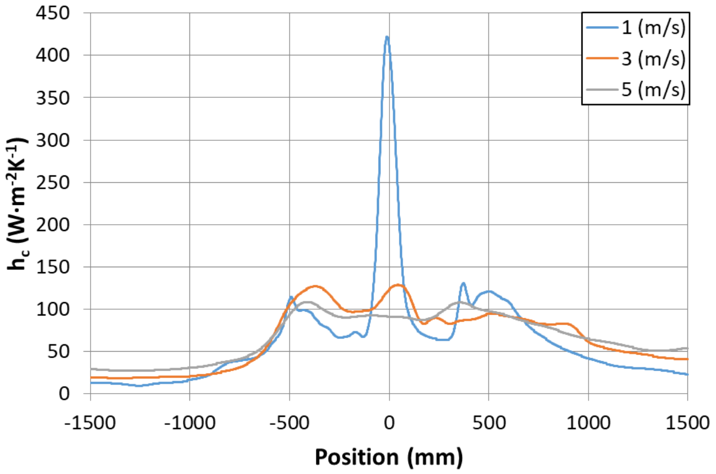

Figure 4 Heat transfer coefficient for surface temperature 800–900 °C for forced convection by water on the moving bloom surface depending on position under the cooled work roll

4. CONCLUSION

Heat losses caused by radiation, free convection into the ambient air, forced convection into the ambient air and into the water during hot rolling of the bloom were investigated using laboratory experiments. The measurements were evaluated to obtain information about heat loss on a dry stationary bloom, on a dry moving bloom and on a moving bloom hit by water coming from spray cooling of the roll.

The results show that the highest heat loss is caused by radiation; its values are 88–171 $W \cdot m^{-2} \cdot K^{-1}$ for surface temperatures of 800–1,100 °C. The heat loss due to residual water from work roll cooling decreases as movement velocity increases, ranging from 80 to 88 $W \cdot m^{-2} \cdot K^{-1}$. The heat loss caused by forced air increases as movement velocity increases, ranging from 13 to 29 $W \cdot m^{-2} \cdot K^{-1}$. The emissivity coefficient was found to be 0.84 for a surface free of scales and 0.92 for an oxidized surface with roughness of approximately Ra = 3 μm.

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