EFFECT OF THE SPEED OF FEEDSTOCK ON HEAT TRANSFER COEFFICIENT DURING DESCALING IN HOT ROLLING

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Abstract

Hydraulic descaling is essential to obtaining a high-quality surface in hot-rolled steel. Descaling removes mill scales (mainly iron oxides) from the surface using high-performance water jets which break the structure of the scales and washes them off the steel strip. The strip is then hot rolled. The speed of the feedstock in a mill directly affects the productivity of the line but can negatively affect the surface quality of the rolled steel, since part of the surface may not be descaled properly if the feedstock moves too quickly. Descaling itself combines both mechanical and thermal effects. The available literature attributes merits to both types of effect, and both are always present in the process. The process of descaling was examined in experiments with a standard descaling nozzle for speeds from 0.1 m/s to 2 m/s. The position-dependent values were computed by an inverse task and the heat transfer coefficient was obtained. The experiment with the slowest speed showed a very intense and relatively long-lasting cooling. A change of cooling regime was observed for speeds up to 0.5 m/s, where the average heat transfer coefficient gradually decreased with the speed. The article summarizes these findings and gives insight into various aspects of the hot rolling process.

Keywords: Hot rolling, descaling, heat transfer coefficient, inverse heat conduction task

1. INTRODUCTION

Hydraulic descaling is essential to obtaining high-quality hot-rolled steel. Unwanted scales on the surface of the feedstock are removed by a water jet and washed away. As a multifactor process, descaling conditions can vary significantly. The most crucial factors that affect the process are nozzle type, nozzle configuration, material and the temperature of the descaled steel.

The water jet causes thermal shock on the surface [1] and plays a key role in crack formation in the layer of scales as well as in the final microstructure of the surface of the steel [2]. The cooling intensity can be quantified by a heat transfer coefficient *h.* Published models of hot rolling based on experimental data operate with a constant value of heat transfer coefficient in the section where the jet directly sprays the surface. The values reported in [3] and [4] vary from 1 162 W/m^{2}K to 20 920 W/m^{2}K. Article [5] states that the heat transfer coefficient is a linear function of the impact pressure of the water jet and the values vary in range from 28 500 W/m^{2}K up to 43 000 W/m^{2}K for impact pressures in range from 0.48 MPa to 0.8 MPa. Article [2] uses values in the range from 2 000 W/m^{2}K to 8 000 W/m^{2}K for different levels of spray pressure.

As has been illustrated, due to the complexity of the process, the outcomes of experiments cover a very wide interval of values. The aim of this paper is to study the relationship between the speed of the feedstock and the heat transfer coefficient. The paper is focused on the relationship and the position where most of the cooling takes place rather than on specific values for the heat transfer coefficient for this particular case.

2. NOZZLE CONFIGURATION

A standard descaling nozzle was chosen for this study. The nozzle had a typical descaling flat jet with 45° spray angle and produced 41 l/min at 20 MPa. This nozzle was also used in study [6]. The pressure distribution given by this nozzle was very close to rectangular and thus it was safe to assume homogeneous descaling along the width of the feedstock. The system pressure was set to 20 MPa. The nozzle was placed 93 mm above the surface of the feedstock, the inclination angle was set to 15° and the twist angle was set to 0°. This means that the footprint of the jet on the surface was perpendicular to the vector of velocity of the feedstock. The nozzle configuration is shown in **Figure 1**.

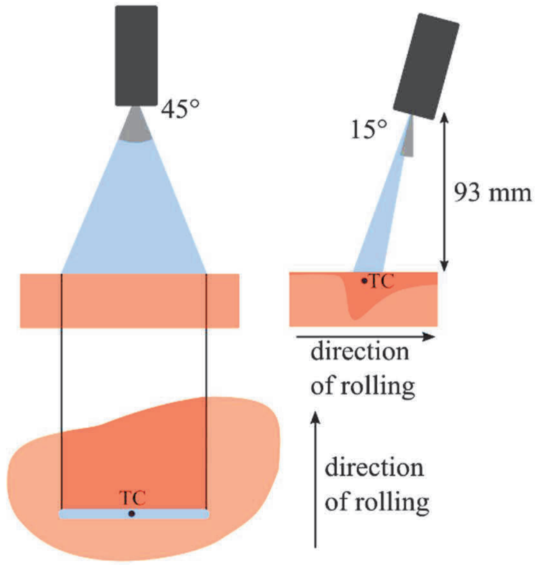

Figure 1 Diagram of the nozzle configuration

3. EXPERIMENTS

Experiments were performed on a laboratory bench. The diagram of the bench is shown in **Figure 2**. The descaling process was examined for speeds 0.1 m/s, 0.5 m/s, 1 m/s and 2 m/s. The speeds from 0.5 m/s to 2 m/s represent typical speeds which can occur on a hot rolling line in a mill. The tested specimen was placed onto a moving carriage and equipped with a grounded thermocouple under the surface. The specimen was heated in an electric heater to a temperature of 900 °C (850 °C for the experiment with the slowest speed). Then, the carriage was turned and driven at the desired speed under the spraying nozzle. A datalogger attached to the carriage collected position data and the corresponding measured temperature at the thermocouple during the experiment. After the experiment was done, data was gathered in a computer and further processed.

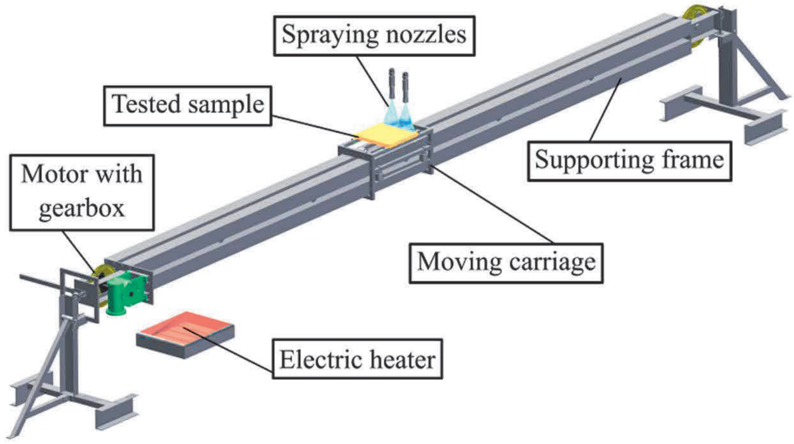

Figure 2 Diagram of the laboratory bench

4. DATA PROCESSING

Raw data from the experiment consisted of position-dependent temperature at the thermocouple. The temperature at the surface and the heat transfer coefficient were obtained using an inverse heat conduction task.

The inverse heat conduction task used a given set of measurements from the thermocouple inside the specimen and a direct heat conduction task computed the boundary conditions of the model (i.e. the temperature at the surface of the specimen). The algorithm used the sequential identification inverse method, described in detail in [7]. This algorithm minimized the mean square error of the difference between the measured temperature and the temperature computed by the model.

A typical set of data is shown in **Figure 3**. The heat transfer coefficient is dependent on the position of the nozzle jet footprint and the carriage. The scale of position was chosen such that the zero value corresponds to the maximum value of heat transfer coefficient.

Due to the limited speed of propagation of the cooling impulse in the specimen, the temperature measured at the thermocouple is delayed and blurred. This blurring of original data also transfers to the computed data and blurs the heat transfer coefficient values with respect to the time scale. This leads to bias in the computed data and the maximum heat transfer coefficient value is very often underestimated at the expense of the lap of the intense cooling impulse, which is overestimated. This algorithm partially compensates for this blurring with a very fast drop of the coefficient value and by creating a second smaller peak. This peak has no physical meaning and is caused only by the algorithm used.

The average value of the heat transfer coefficient was computed in a section from position -50 mm to position +50 mm. The average value partially compensates for the bias of the outcomes and allows individual measurements to be compared.

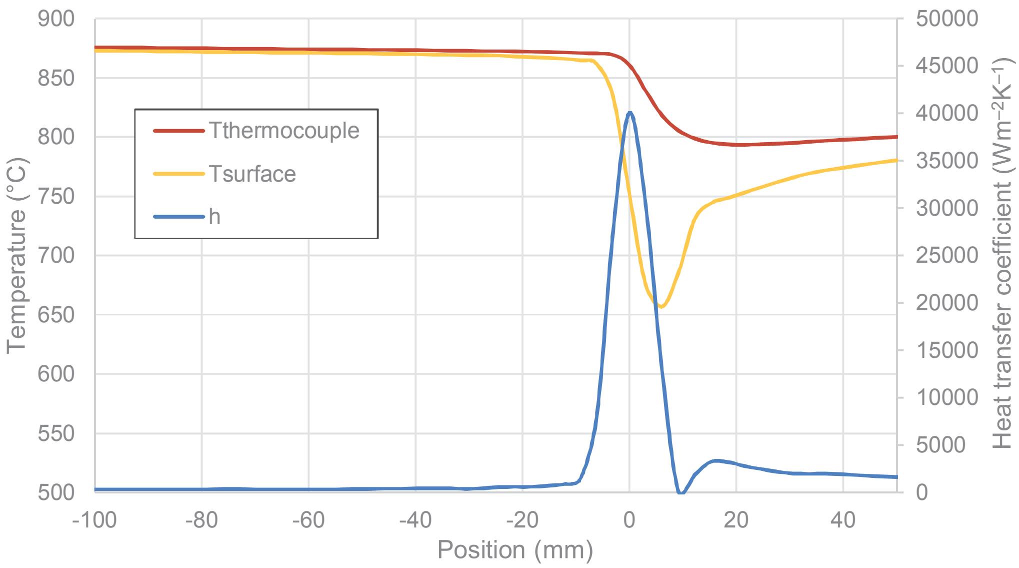

Figure 3 Measured thermocouple temperature with respect to the position of the carriage. The temperature on the surface and heat transfer coefficient *h* was computed by the inverse task algorithm.

5. RESULTS

The results of the experiments are shown in **Figures 4, 5** and **6**. **Figure 4** shows the raw data of temperatures measured by the thermocouple. The experiment run with the speed of 0.1 m/s is detached since the starting temperature of the experiment was 850 °C. All experiments showed a maximum temperature drop at the location of the jet footprint (position 0). This declining trend stopped as the specimen recovered from the thermal shock. The most visible recovery was observed in the experiment with the slowest speed. At position close to 30 mm behind the jet footprint, the temperature very quickly changed its gradient. The temperature change was gradual for the other experiments.

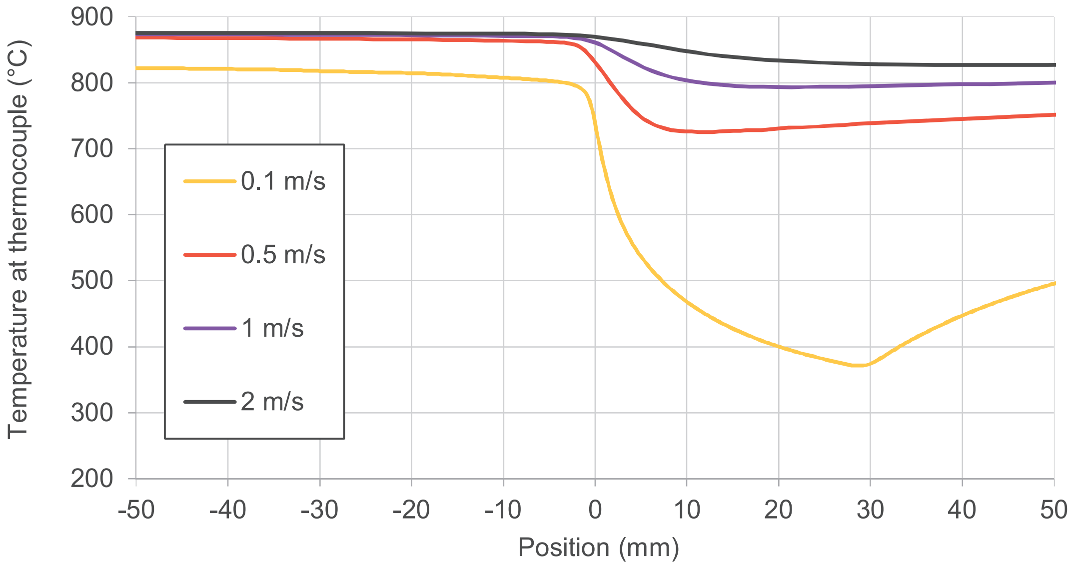

Figure 4 The temperature of the thermocouple with respect to the position of the carriage and its speed

The analysis of the measured data indicated the temperature conditions on the surface of the specimen. The outcomes are shown in **Figure 5**. The maximum temperature drop varies from 124 °C for the experiment with speed of 2 m/s to 604 °C for the experiment with the speed of 0.1 m/s. Due to the reasons described in Section 4, the absolute values of temperature drop must be treated with caution. The thermal shock could be even higher due to this bias.

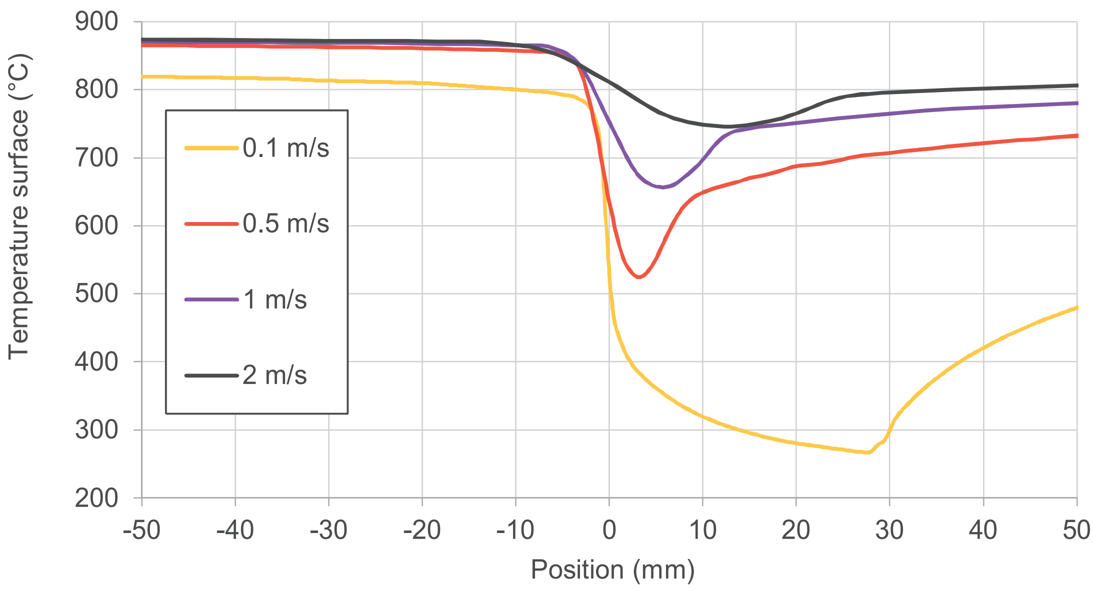

Figure 5 The temperature of the surface with respect to the position of the carriage and its speed

The corresponding heat transfer coefficients are shown in **Figure 6**. Experiments for speeds from 0.5 m/s to 2 m/s are characterized by single peak functions which drop very quickly. In contrast, the experiment with a speed of 0.1 m/s showed intense cooling even in the section behind the water jet footprint. The significant cooling of the surface took place in almost 30 mm, even though the water jet footprint was only several millimeters [5]. The heat transfer coefficient grew rapidly when the jet hit the surface but faded very slowly with a fast drop at 30 mm. The reason for this extension may lie in the intense cooling of the surface under the Leidenfrost temperature where the evaporation of water becomes very quick and effective [8]. This experiment refutes the assumption that intense cooling takes place only at the water jet footprint.

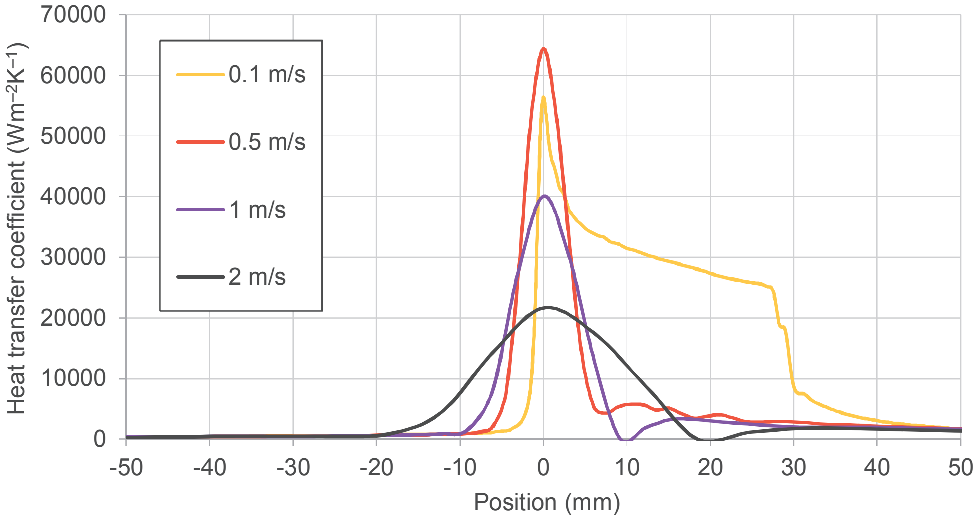

Figure 6 Heat transfer coefficient with respect to the position of the carriage and its speed

The average heat transfer coefficients with respect to speed are shown in **Figure 7**. The experiment with the slowest speed is detached due to the reasons mentioned earlier. The remaining experiments show a slight decrease of average heat transfer coefficient with respect to the speed of the feedstock. The values were 5 521 W/m^{2}K, 4 722 W/m^{2}K and 4 521 W/m^{2}K for corresponding speeds of 0.5 m/s, 1 m/s and 2 m/s. Taking 1 m/s as the normative speed of hot rolling, decreasing the speed to 0.5 m/s causes a 17 % increase of the average heat transfer coefficient. Increasing the speed to 2 m/s causes a 4 % decrease in the average heat transfer coefficient.

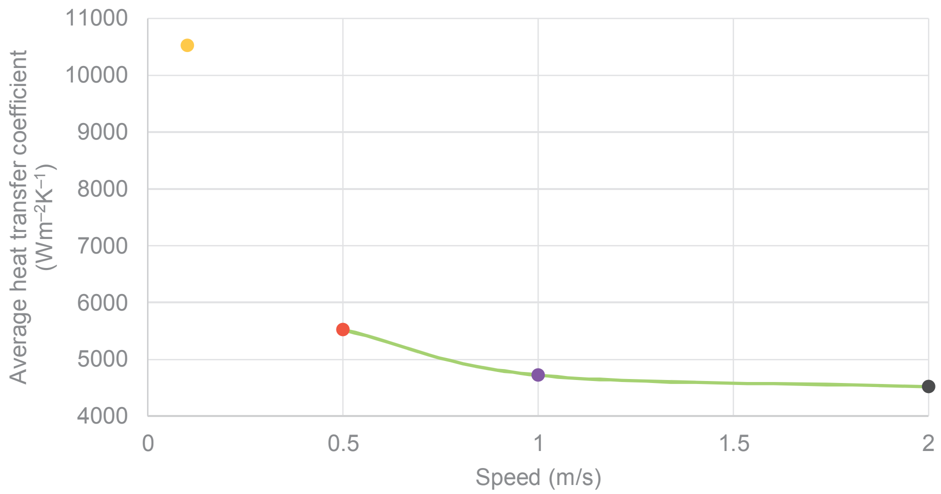

Figure 7 Average heat transfer coefficient with respect to the speed of the carriage

6. CONCLUSION

The experiments examined the relationship between the speed of the feedstock and the heat transfer coefficient during descaling. Experiments confirmed the decrease of the heat transfer coefficient when increasing the speed of the feedstock.

The values of the average heat transfer coefficient for speeds that can be compared to operating speeds at rolling mills were within the range of 4 521 W/m^{2}K to 5 521 W/m^{2}K. These results fully corresponded to spans presented in [2], [3] and [4]. The maximum values of the heat transfer coefficient were between 64 410 W/m^{2}K and 21 637 W/m^{2}K and were similar to the results described in [5]. Taking the speed of 1 m/s as a normative, a reduction of the speed by half increased the heat transfer coefficient by 17 %. Doubling the speed to 2 m/s decreased the heat transfer coefficient by only 4 %.

The experiment performed at 0.1 m/s showed that very intense cooling may take place even beyond the place where the water jet hits the surface. The average heat transfer coefficient was 10 522 W/m^{2}K and the maximum value was 56 390 W/m^{2}K. At these unusually slow speeds, temperatures at the surface may go under the Leidenfrost temperature and this may intensify the full process.

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