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Influence of parameters of hydraulic descaling on temperature losses and surface quality of rolled material

Hydraulic descaling is a process of removing the oxide from the hot steel surface. Surface quality after descaling is fundamental for the final surface quality of a roll product. Aspect of heat extraction, as a part of descaling process, is not usually seriously considered. Surface sub-cooling can negatively influence the demanded temperature field in the rolled material. The main goal of the paper is to show how the setting of hydraulic descaling parameters can influence heat transfer and the final temperature field in the rolled material.

Experimental work was concentrated on the study of descaling in relation to heat transfer and the quality of scale removing from the surface. Two types of measurements were implemented. The first one is a measurement of temperature drop when a product is passing under the nozzle (heat transfer test). The second type is a study of the surface quality where a defined layer of oxides is sprayed and its remaining thickness is evaluated. The heat transfer test is evaluated by inverse task and the results are prepared in a form of boundary conditions suitable for using in the numerical model.

The computation done by numerical model of descaling demonstrates the influence of various parameters on the process efficiency. Understanding of the hydraulic descaling mechanism enables the optimization of spraying parameters and its influence on the rolling technology.

Hydraulic descaling extracts intensively heat from the sprayed material. The setting of the parameters of sprays can control temperature losses due to the descaling. Thermal losses affect the demanded furnace temperature and they have economic consequences as well.

The intensive heat transfer during hydraulic descaling caused sharp temperature drops in the surface layer of material. This can cause problem when material with strongly non-homogeneous temperature enters the rolling gap. The surface temperature can drop down in hundreds of degrees.

The high-pressure spray process is used mostly as an intermediate step between continuous casting and hot rolling or at several positions of rolling train. The oxides are removed of the surface by two major mechanisms. The first one is a local quenching of the surface causing thermal stresses between layer of oxides and compact material. The second effect is a dynamic force of impacting water jet.

The thermal stresses are significantly influenced by the dynamic of heat transfer process. The parameter, describing intensity of cooling, is a heat transfer coefficient (HTC) distribution in the impact area. Heat transfer coefficient is dependent on the nozzle type, water pressure, water temperature, surface temperature, position (spray height) of nozzle from surface and velocity of the material under the jet [1]. The value of local impact forces plays the major role in the mechanical part of descaling.

Experimental equipment

The experimental stand was built to study the cooling of linearly moving objects. A six-meter-long girder carrying a movable trolley and a driving mechanism, **see Figs. 1 and 2**, form the basic part of the experimental device. An electronic device measuring the position of the trolley is embedded in the trolley. The driving mechanism consists of an electric motor controlled by a programmable unit, a gearbox, two rollers and a hauling rope. The girder is divided into three sections. The marginal sections are used for the trolley's acceleration or deceleration. The velocity of the trolley is constant in the mid-section and it is here where the spray nozzles quench the measured sample.

Heat transfer measurement

The tested plate with embedded temperature sensors is placed on a track. An example of the typical size of the tested plate can be seen in **Fig. 3**. The sensors measure the temperature at a depth of 1 mm from the cooled surface.

Experimental procedure.

- An electric furnace (heater) heats the tested plate to an initial temperature of the experiment.
- The water pump is switched on and the pressure is adjusted.
- A driving mechanism moves the tested plate under the spray.
- The sensors indicate temperature in the tested plate. Temperature is recorded into data logger memory.

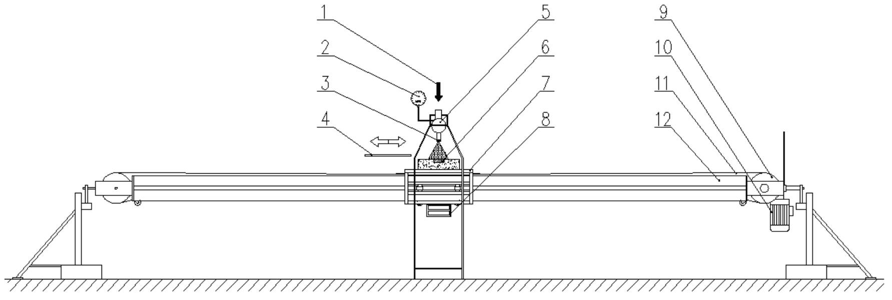

Fig. 1: Principal scheme of the laboratory test bench: 1) cooling medium, 2) pressure gauge, 3) nozzle, 4) moving deflector, 5) nozzle manifold, 6) test plate, 7) moving trolley, 8) data logger, 9) roller, 10) electric motor, 11) hauling wire rope, 12) girder.

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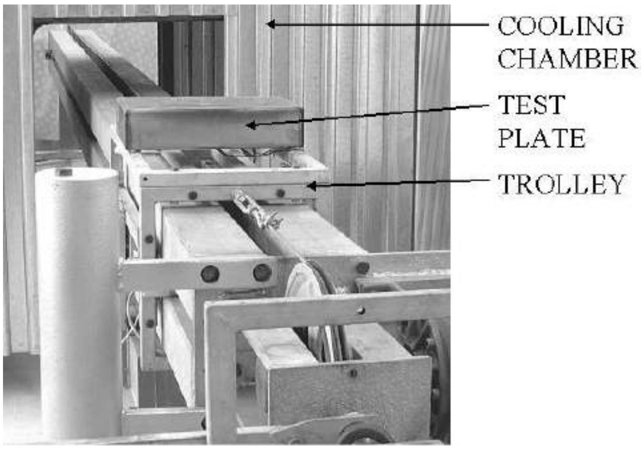

Fig. 2: Photo of linear test bench.

- The position of the tested plate in the direction of movement is recorded together with the temperature values. The record of instant positions is used for the computation of instant velocities while moving under the spray.

The pass under the nozzle causes a temperature drop in the material sample that is indicated by the temperature sensors. This information, together with material properties and calibration characteristics of temperature sensor, is used as an input for the inverse heat conduction task.

Inverse heat conduction task

Basic part of the inverse task is numerical 3D model of the tested plate and sensors. The temperature distribution inside the tested specimen is described by the following Equation 1.

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)=\rho c\frac{\partial T}{\partial t} \quad (1)$$

where T is temperature, t is time, x, y, z are space coordinates, k is for thermal conductivity, c is for thermal capacity and ρ is for density.

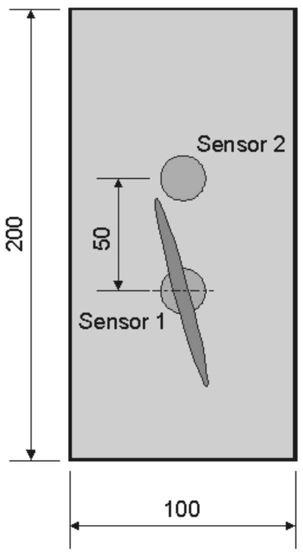

Fig. 3: Tested plate - geometrical arrangement, one nozzle measurement.

Direct solution of this equation can be done relatively easily using a numerical technique, with the knowledge of thermo-physical material properties and boundary conditions.

Inverse task means, in this case, finding the boundary conditions (HTC on the surface) from the temperature measured inside the specimen. Temperature histories are taken from the experiment when a sensor is positioned inside the specimen. The method used here is based on a minimization principle [2]. Basic part of this procedure is scheme of heat transfer coefficient computation at time M. An example of this scheme is shown in **Fig. 4**. The direct computation is branched-out at time M-1. Two different values of HTC are applied for a certain number of forward steps r. The HTC h^* minimizes mean square root deviation between computed $T_{h_j}^i$ and measured $T_{\exp}^i$ temperatures.

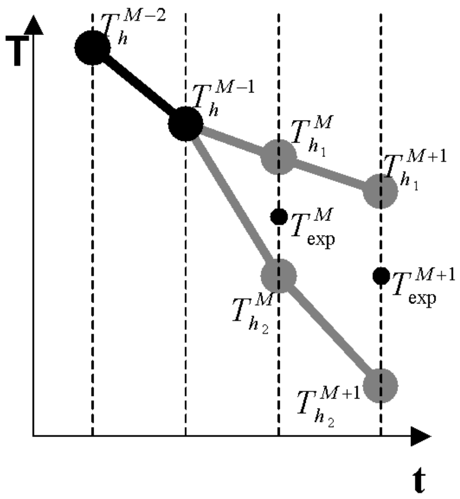

Fig. 4: Inverse computation scheme.

$$S=\sum_{j=1}^{r}\left(T_{exp}^{j}-T_{h^*}^{j}\right)^2 \quad (2)$$

Then the optimal value of HTC h^* can be expressed as (details in [2]):

$$h^*=\frac{\sum_{i=1}^{r}h_1 {D^i}^2+\sum_{i=1}^{r}(T_{\exp}^i-T_{h_1}^i)D^i}{\sum_{i=1}^{r}{D^i}^2} \quad (3)$$

where D^i is sensitivity coefficient which can be numerically estimated as:

$$D^i=\frac{T_{h1}^i-T_{h2}^i}{h_1-h_2} \quad (4)$$

For the extremely intensive heat transfer the numerical procedure, which increase precision of the computed values in HTC peaks, can be applied. Details of this procedure are out of scope of this paper and can be found in [3].

Results

Heat transfer tests. An example of the measured and evaluated data is given in **Figs. 5 and 6**. The tested plate during the heat transfer tests runs several times under the spray. The record in Fig. 5 is for ten runs. Sharp drops on the temperature curve indicate the positions of spray. The temperature is measured inside the tested plate. The bold line is for the measured temperature history. The surface temperature history is obtained from the inverse task. It can be seen that temperature fluctuations of the sprayed surface reaches about 60°C in this experiment. The other result of the inverse task is heat transfer coefficient history and heat

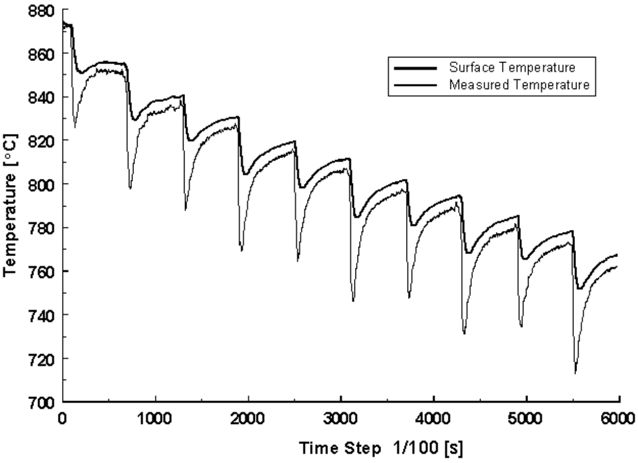

Fig. 5: Temperature history in sensor position and computed surface temperature history.

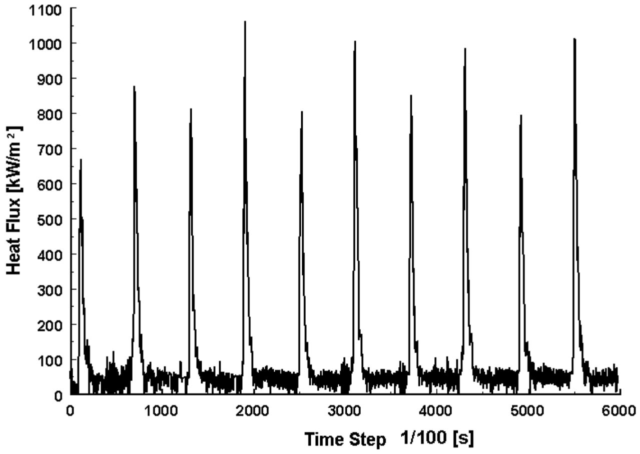

Fig. 6: Computed heat flux history in nozzle axis.

flux history. The heat flux is plotted in Fig. 6. The sharp peaks are formed in position of surface spray. **Figure 7** shows the results of three experiments with three water pressures. It can be seen that the heat transfer coefficient grows with the growing water pressure. It should be mention that the heat transfer is strongly influenced by the velocity of the material under the spray. The influence of the pressure used for descaling can be seen in the following numerical example.

To examine the temperature drop of the cooled surface a computational experiment was performed using experimentally obtained data. A carbon steel plate (C=0.2%) with the thickness of 150 mm was descaled. The slab initial temperature was 1000°C. One pass under the nozzle was examined for the pressures of 50, 150, and 450 bar. The boundary conditions given in Fig. 7 are used for the computation. The computed surface temperature history, temperature history for 1 mm and 5 mm under the cooled surface is shown in **Figs. 8-10**. The surface temperature drop for 450 bar was 155°C, while for 50 bar it was 92°C. Fig. 10 shows that the temperature drop for 5 mm under the surface is smaller than 9°C.

Quality test

Final surface quality after descaling is, for most users, more important parameter than the material sub-cooling by sprays. Impacting water removes the scales and the final quality of surface is affected by spray parameters [1].

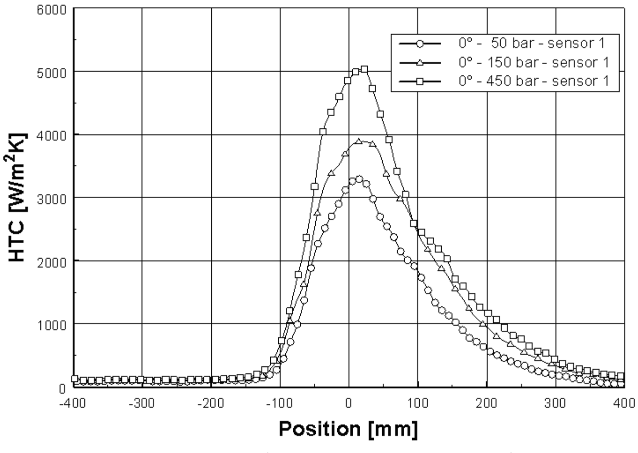

Fig. 7: HTC distribution for tests with pressure of 50; 150 and 450 bar. Inclination angle 0°.

Steel test plates are used for the quality tests. The plates are heated and a defined layer of scale is prepared. The preparation of the demanded layer of scale is the most crucial part of the experiment.

As soon as the tested plate is at the starting temperature and the surface is properly oxidized the tested plate is moved to the track and placed on the test bench. The spraying part of the experiment is the same as in the above mentioned heat transfer test. The tested plate goes through the spray chamber, see Fig. 2. The final structure of the scale after descaling is frozen in nitrogen box where the tested plate cools down.

Scale thickness measurements

The tested plates show two areas, see **Fig. 11**. In the central part of the tested plate can be seen a noticeable area, (nozzle footprint). On the sides of tested plate the original layer of scale can be seen, (outside nozzle trace).

The most precise way of thickness measurement and study of the scale morphology is usage of electron microscope. An electro magnetic probe can be used for the measurement of the scale thickness. This method provides averaged values of certain area.

The areas with various thicknesses of scales remain in the sprayed footprint. In the other words – the scale layer has not usually constant thickness. Therefore, the final quality of surface is better to express not only by the average thickness of scales but even by the percentage quantity of remaining scales as well. This is calculated from the quantity of remaining scales in the nozzle footprint referenced to the total quantity of scales that are on given area before spraying.

The correlation between quality and spraying parameters, e.g. pressure, type of nozzle, spray height, inclination angle and velocity, is studied. An example of the parameter study is given in the **Fig. 12**. The influence of the impact pressure and sample velocity on the surface quality is shown here. The water-spray impact pressure is approximately linearly dependent on the water pressure. Water-spray impact pressures decreases with the spray height. **Table 1** shows the values of impact at a distance of 150 mm and three water pressures of 50, 150 and 450 bars respectively.

Figure 12 shows the best surface quality for the highest impact and a velocity of 1.0 m/s.

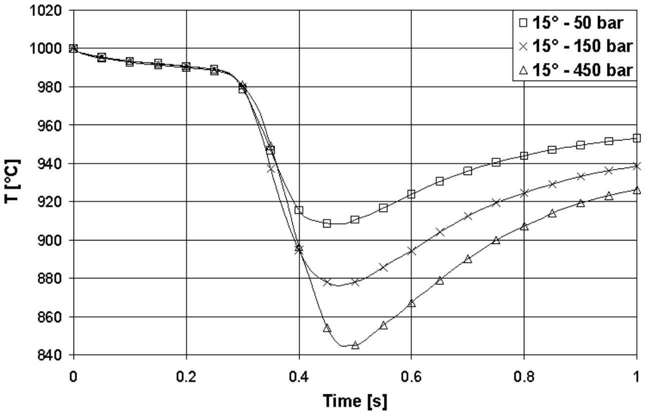

Fig. 8: Computed surface temperature history.

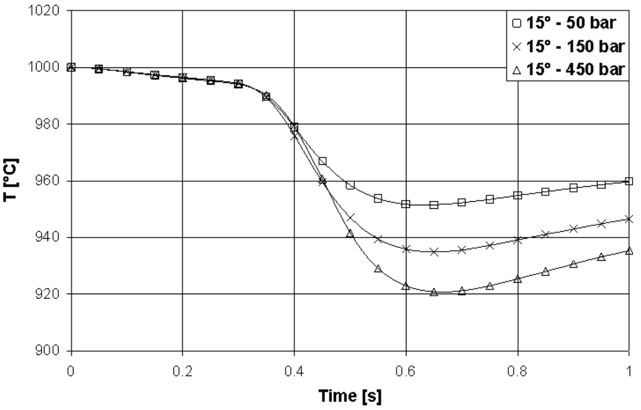

Fig. 9: Computed surface temperature history 1 mm under the cooled surface.

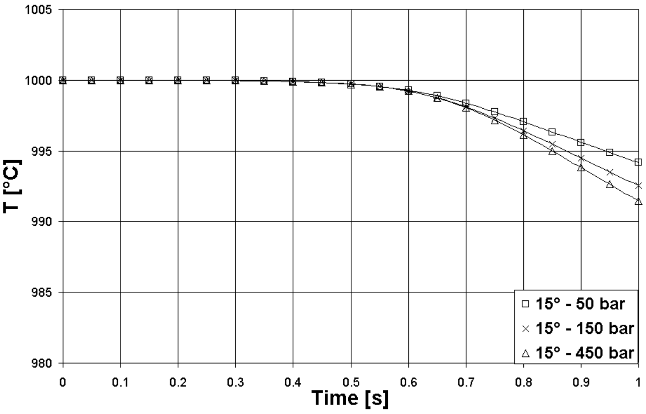

Fig. 10: Computed surface temperature history 5 mm under the cooled surface.

Conclusions

- Thermal aspects of descaling process are discussed in this paper. Considering the temperature of the material as the main parameter for its formability the influence of hydraulic descaling was experimentally studied. It was shown that water pressure in descaling system can significantly affect intensity of cooling. Similar effect was observed when changing the velocity of the sprayed material.

Table 1: Impact, spray height of 150 mm and water pressures of 50, 150 and 450 bar.

Pressure [bar]	Flow rate [l/min]	Impact [N/mm2]
50	32	0.14
150	55	0.43
450	95	1.30

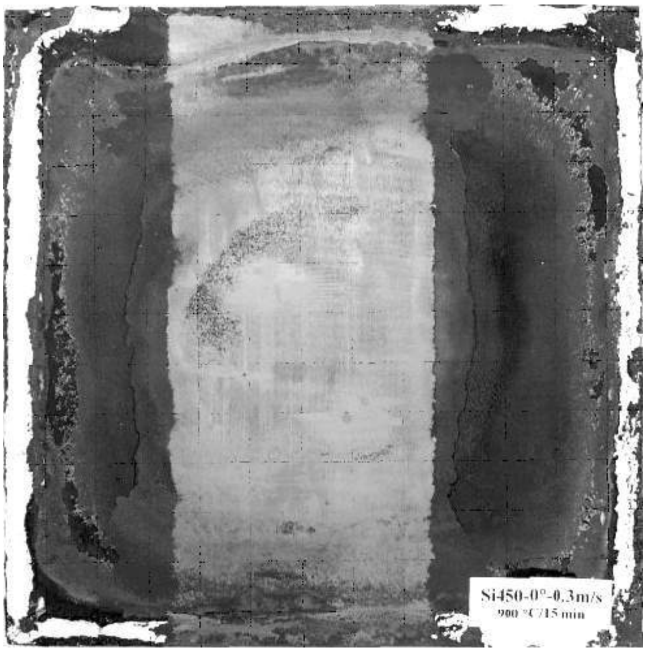

Fig. 11: Photo of plate after quality descaling test.

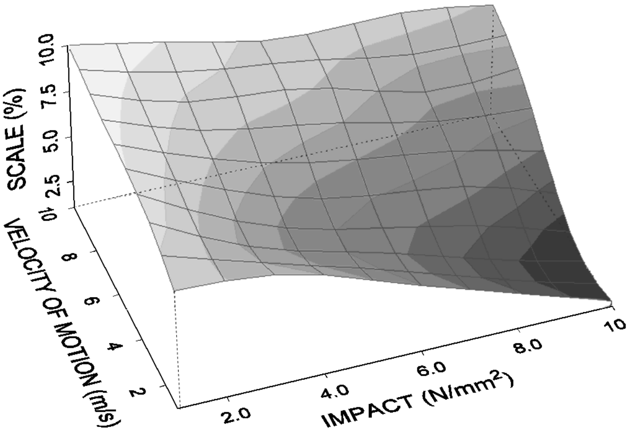

Fig. 12: 3D-diagram: Dependence of remaining scales on the velocity of steel motion on impact pressure.

- Description of the cooling effect can be done only experimentally. The results of experiments use the numerical model of temperature field. The model provides information on heat extraction and temperatures in the surface layer and in the centre.
- Settings of all parameters of hydraulic descaling must be done together with study of the resulting surface quality. The quality tests confirmed the influence of impact pressure and velocity of the sprayed surface. Both of these parameters are quantitatively described.

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