OPTIMAL HYDRAULIC DESCALING

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Abstract

Hydraulic descaling is an inherent part of the hot rolling process but can sometimes also be applied in the heat treatment process, continuous casting and other processes. The need for optimal descaling is linked with the quality of the final product. The goal is usually simplified to the complete removal of the scale layer from the hot surface. The descaled surfaces are often wide and a number of nozzles must be used. The quality problems are almost exclusively connected with the overlap of water jets. An experimental study of overlap optimization is presented in this paper. A new approach using in-line configuration of jets is introduced and discussed. This paper also describes why even the completely oxide-free surface achieved after descaling the unit can be a far from optimal solution. Thermal strips on the hot surface cause much more intensive oxidation of the hot part and much slower oxidation in the cold strips on the descaled surface. The speed of oxide formation on the steel surface is exponentially dependent on the surface temperature. Temperature non-homogeneity after descaling in the rolling process can cause the same defects on the surface of the final product as poor descaling. Temperature aspects with links to heat loss and secondary oxidation are discussed.

Keywords: Descaling, hydraulic, nozzle, hot rolling, overlap

1. INTRODUCTION

Hydraulic descaling is essential to obtain high-quality hot-rolled steel. Scales on the surface of the rolled material are removed by a water jet and washed away [1,2]. As a multifactor process, descaling conditions can vary significantly. The most crucial factors that affect the process can be divided into mechanical effects and thermal effects [3,4]. The dominant parameter is impact pressure, influencing both mechanical and thermal action [5,6]. The impact pressure depends on nozzle feeding pressure, nozzle quality and nozzle standoff from the descaled surface [7–9]. For descaling purposes the following parameters must be studied: impact distribution along the spray angle of a single nozzle and impact distribution in an overlap area, where there is interaction of jets from neighboring nozzles [10].

The water jet causes thermal shock on the surface [11,12] and plays a key role in crack formation in the layer of scales. The cooling intensity can be quantified by a heat transfer coefficient. Published models of hot rolling based on experimental data operate with a variable value of heat transfer coefficient in the section where the jet directly sprays the surface. The values reported in [13] vary from several hundred $W.m^{-2}.K^{-1}$ to 20 920 $W.m^{-2}.K^{-1}$. Article [14] 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 290 000 $W.m^{-2}.K^{-1}$ to 420 000 $W.m^{-2}.K^{-1}$ for impact pressures in the range 0.48 MPa to 0.8 MPa. The authors of the paper [15] measured heat transfer coefficient values under flat jet nozzles and it was found that cooling intensity does not increase linearly with pressure, but some saturation can be observed at high pressures. This finding is consistent with the statement that a maximum possible heat transfer coefficient value exists for forced convection and convection with phase change [16]. The heat transfer coefficient is also a function of surface temperature during water cooling and the increase in water pressure also raises the Leidenfrost temperature [17]. The situation during descaling can be even more complex when the authors consider the presence of oxides on the surface [18,19] and surface roughness [20] when studying heat transfer. As has been illustrated, due to the complexity of the process, the outcomes of experiments cover a very wide range of values.

There are some parameters which can play only a minor role but should be considered in the design of the descaling unit [21]. Thermal losses are a limiting factor for some technologies [22]. The velocity of the descaled surface has a major effect on thermal losses during descaling; this is described in [23]. The Korean company POSCO studied the possibility of modifying thermal losses by modifying the water temperature; the results of this interesting study are published in [24].

This study presents experimental methods which can help us to design the descaling units correctly. Experience from industry indicates that the main problems are in the geometrical configuration of nozzles. In other words, designing the descaling unit with a proper spray overlap is difficult [25]. An experimental study confirmed that having neighboring jets which collide with each other can significantly reduce descaling performance [10] and significantly increase cooling [4]. Industrial descaling units usually have nozzles rotated by offset angle β set to 15° (see **Figure 1** right) to avoid the water jets colliding before the water hits the descaled surface [5,7,25–32]. The only exception are patents [33,34] where the offset angle is set to 0° but the configurations produce two discontinuous lines trying to avoid problem in overlap area. Study of the overlap area in the author’s laboratory led to the idea of an in-line nozzle configuration which has been successfully tested in industry and is introduced in this paper and compared with classical configuration using several types of laboratory measurements.

2. LABORATORY MEASUREMENTS

Laboratory measurements provide information about the magnitude of impact pressure caused by water jets from descaling nozzles hitting the descaled surface, and also about impact distribution, heat transfer from the descaled surface and surface quality after descaling.

Figure 1 shows a diagram of impact pressure distribution measurements. The important feature of the device is that the impact is measured by a sensor embedded in a flat plate. Only this approach allows us to study interaction of sprays in the overlap area where the deflected water jet can significantly influence the jet from the neighboring nozzle. Examples of these measurements are shown in **Figure 2**.

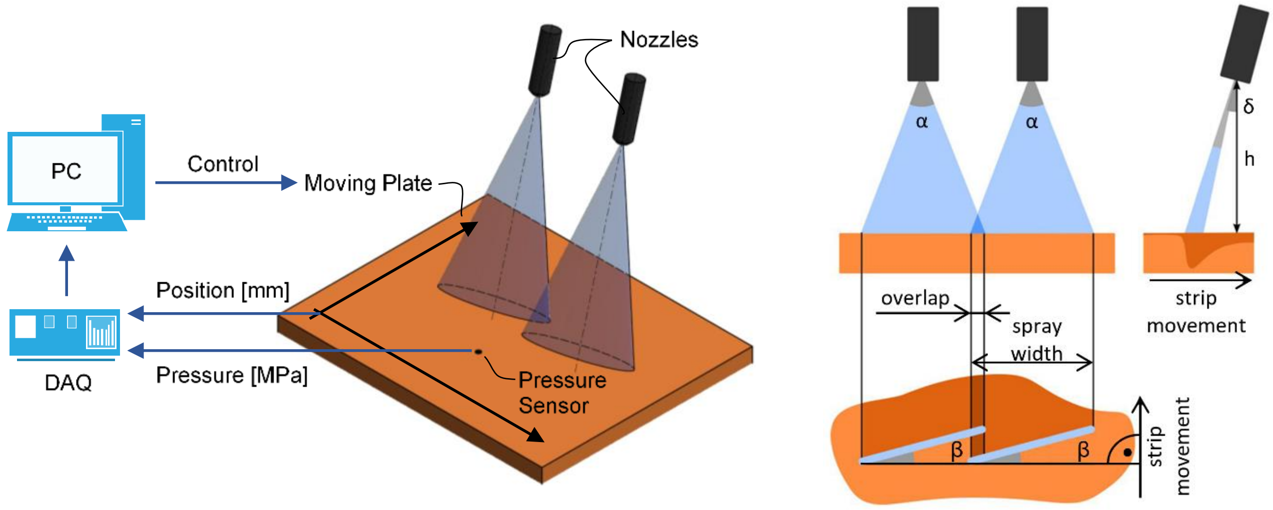

Figure 1 Diagram of impact pressure distribution measurement (left); diagram of nozzle configuration (right)

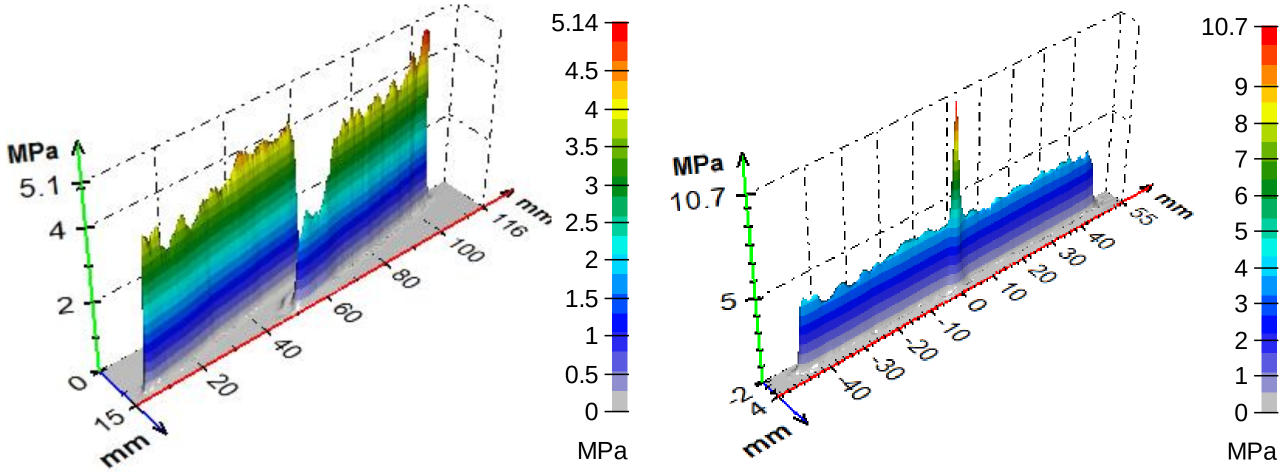

Figure 2 Impact pressure distribution measurement of two configurations: left is with offset angle β=15° (standard configuration) and right is with offset angle β=0° (in-line configuration)

The effect of the impact of the water can also be studied through erosion tests. Industry commonly uses painted steel plates to check descaling systems. Erosion tests use aluminum plates or plastic materials. The examples shown in **Figure 3** are for tests with movement of the tested surface and for static tests. Static erosion tests are not suitable for study of the overlap area because the water jet digs a slit in the plate and the direction of the reflected water in the test is different to the direction of the water in the rolling plant, where it has a flat surface.

Heat transfer measurements are done using a hot moving test plate manufactured from heat resistant austenitic stainless steel to protect the surface from severe oxidation. The velocity of movement is identical to the velocity in the studied rolling plant. Details can be found in [15]. **Figure 4** shows a very instructive picture of the hot steel plate after being run under two descaling jets. It is evident that the overlap area is subcooled, and the cold strip is visible on the surface. The right part of **Figure 4** shows the measured variations of surface temperature across the width of the surface using an infrared line-scanner placed 0.5 m beyond descaling. To study the heat loss during hydraulic descaling, the hot test plate is equipped with thermocouples (see left diagram in **Figure 5**), which are located 0.6 mm below the descaled surface [4]. Distributions of heat transfer coefficients are computed for each position of the thermocouple (see right graph in **Figure 5**) from the recorded temperature history during the descaling experiment using inverse computation [35]. Lines T1 and T3 are plotted for the area near nozzle axis and lines T2 for the overlap area.

The last type of experiment used in the study of descaling is test of descaling quality [36,37]. The test plate is typically heated with the surface protected against oxidation. The heated plate is first exposed to the oxidation

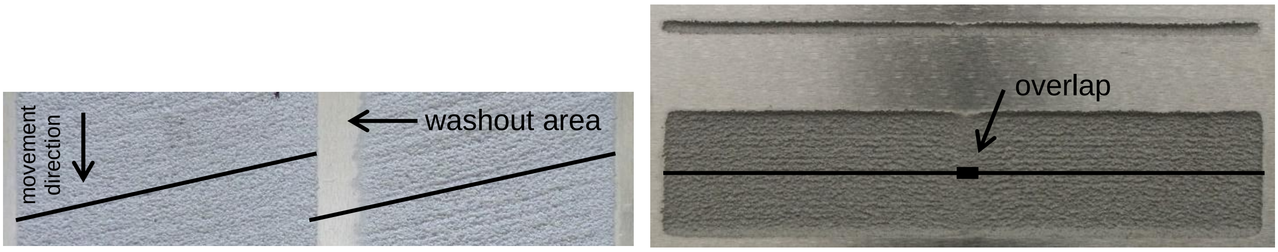

Figure 3 Aluminum plates after erosion tests: the left picture is for a configuration with offset angle β=15° after the erosion test with a moving sample (black lines represent the spray width of each nozzle); the right picture is for an in-line configuration with offset angle β =0° (the upper eroded line shows values after a steady erosion test, while the lower area show a values after an erosion test with a moving sample)

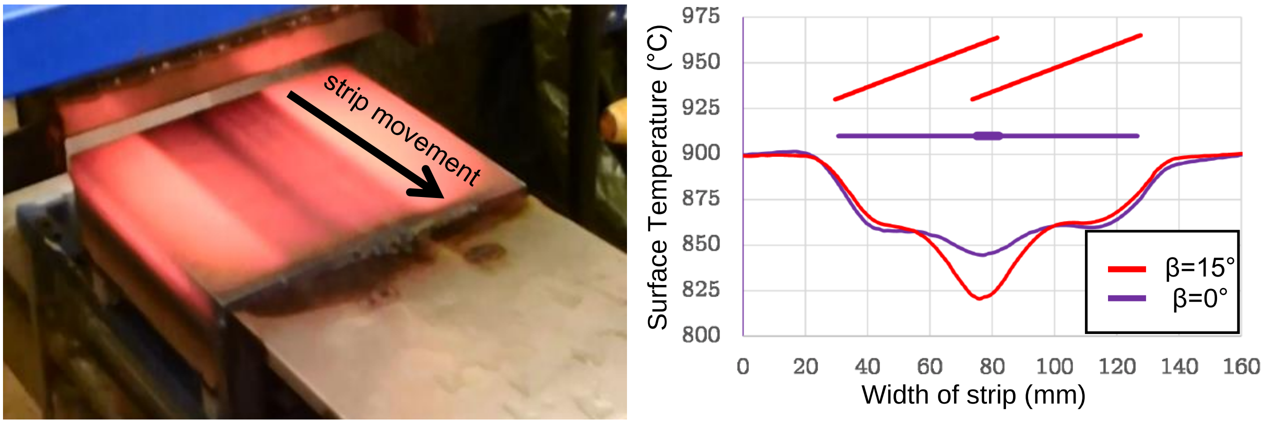

Figure 4 Cooling homogeneity measurements with two nozzles: thermal lines after passing under two descaling nozzles (left photo); measured variations of surface temperature and the sprayed area shown schematically with straight lines in the upper part of the graph (right graph)

for a defined time and then run under the descaling nozzles at the prescribed velocity. Immediately after descaling, the test plate is cooled in a box with a protective atmosphere to protect the surface from further oxidation. Finally, the thickness of the remaining scales is measured after descaling. Examples of the test plates after descaling tests are shown in **Figure 6**. Nozzle arrangements are illustrated by the jets' footprints from the impact pressure distribution measurements.

3. RESULTS – COMPARISON OF STANDARD AND IN-LINE CONFIGURATIONS

The most common configuration (standard configuration) of nozzles in a hydraulic descaling unit for flat products is shown in **Figure** 1 in the right diagram. The offset angle β is usually 15°. The new in-line configuration has the offset angle β set to 0°. The nozzles used for laboratory experiments have a catalogue spray angle of 30°, a water flow rate of 36 l/min for water pressure of 40 MPa, and the standoff was 75 mm.

The results from impact pressure distribution measurements of these two configurations (standard and in-line) are presented in **Figure 2**. It can be observed that the left nozzle has a relatively homogeneous impact pressure distribution, but the right nozzle has low impact values in the overlap area. This is caused by the water deflecting from the left nozzle into the jet of right nozzle. On the other hand, maximum impact pressure is obtained in the overlap area for the in-line configuration. The peak pressure is twice as high as impact pressure under a single nozzle.

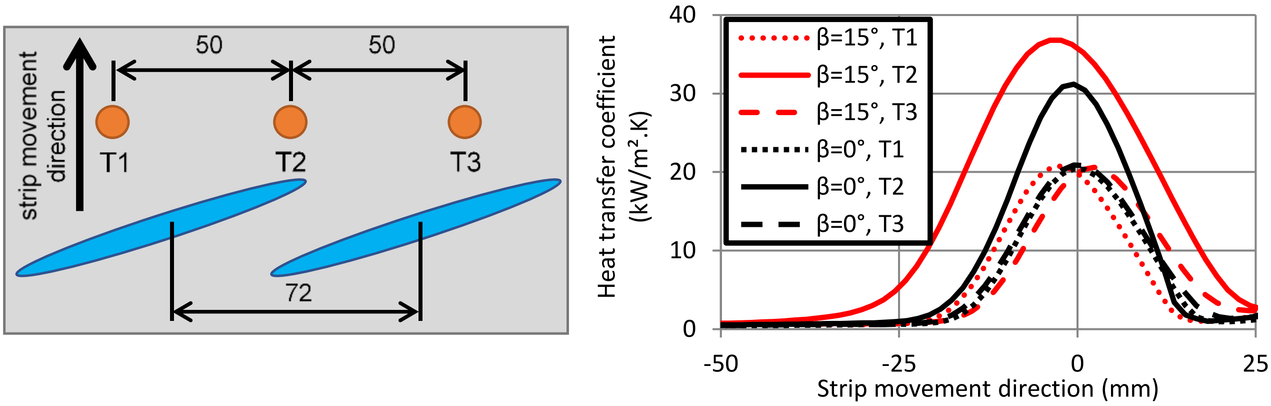

Figure 5 Heat transfer measurements of two spraying nozzles on a moving surface: thermocouple positions (T1, T2, and T3) and impact footprint of sprays for configuration with offset angle β=15° (left picture); measured heat transfer coefficients for two configurations: offset angle β=15° and β=0° (right graph)

The collision between the deflected water and the impacting jet has a significant effect on the quality of hydraulic descaling near the overlap area. The erosion test with a moving plate shown in **Figure 3** (left photo) clearly documents the area where there is no erosion (washout area). The nozzle’s footprints in the impact area are shown by the black lines in **Figure 3**. No washout area was observed in the in-line configuration (**Figure 3**, right photo).

The negative effect of the deflected water in the washout area was confirmed by hot descaling tests for the standard configuration (see **Figure 6**, left photo). The remaining scales here are significantly thicker (12–28 μm) than in the normal area (3–10 μm). Surprisingly, the most descaled area is the overlap area. The in-line configuration does not produce any washout areas and the thickness of the scales is uniform across the strip.

The quality defect in the overlap area described above is not the only problem that can be found in the rolling plant. Let us assume that the surface is perfectly clean after descaling. This fact does not mean that rolling is free of scale-induced problems. **Figure 3** (left photo) shows how non-homogeneous the surface temperature can be after descaling. The dark strip in the overlap area indicates a much lower temperature. **Figure 4** (right graph) shows how significant the decrease in surface temperature caused by descaling nozzles is and how significantly different the temperature in the overlap area and in the area near nozzle axis is. Heat transfer measurements (see **Figure 5**) confirm that the heat transfer coefficient is much higher in the overlap area (T2 curve) for standard configuration with offset angle β=15°. The situation is much better for in-line configuration. The heat transfer coefficient is lower and significantly narrower when comparing "β=0°, T2" with " β=15°, T2". The lower heat transfer coefficient results in reduced heat loss during descaling and the temperature profile is more homogeneous for the in-line configuration with the offset angle β=0° (see **Figure 4**, right graph). Oxidation starts immediately on the clean hot steel surface. Because scale growth rate depends exponentially on the surface temperature, steel with strips that have both thick and thin scales enter the rolling mill and result is often visible in the surface quality when the cooling is not homogeneous across the strip.

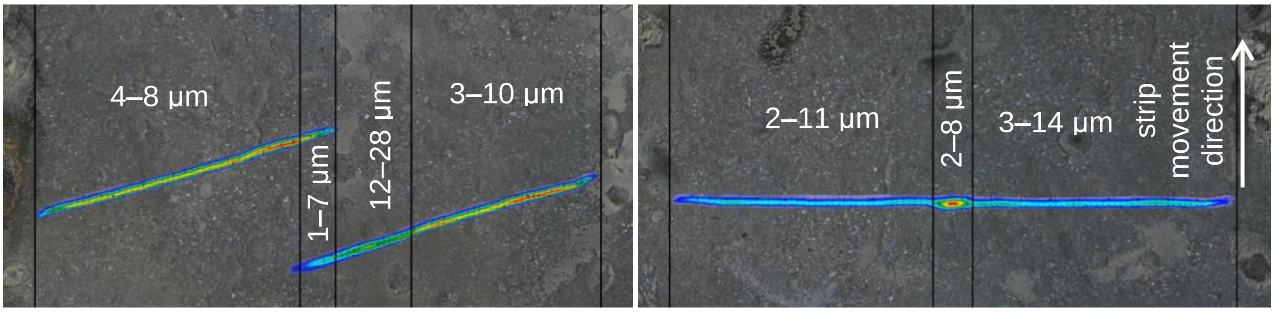

Figure 6 Descaling measurements – thickness of remaining scales: configuration with offset angle β=15° (left picture); in-line configuration with offset angle β =0° (right picture)

Figure 7 Descaling header for use in industry (manufactured by SIGMA DIZ)

Based on the obtained results, a new type of high-pressure spray collector was designed by Brno University of Technology and SIGMA DIZ (see **Figure 7**), which is currently being tested in the company Liberty Ostrava a.s. in Steckel rolling mill. The obtained results are very positive, and the company wants to install new descaling headers with the in-line configuration instead of the standard descaling unit.

4. CONCLUSION

The problems mentioned with overlap cannot be completely eliminated but should be minimized. Testing of the in-line nozzle configuration was motivated by simultaneous optimization of impact and heat transfer. The laboratory measurements confirmed that the negative effect of interaction between deflected water and water jets from the nozzles is more significant for standard descaling configuration with an offset angle $\beta=15°$ than for in-line configuration with an offset angle $\beta=0°$. The experiments also showed that the most problematic area is the washout area and not the overlap area when the descaling unit uses a standard configuration. The positive aspects of in-line configuration were verified in industrial conditions.

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