COOLING HOMOGENEITY MEASUREMENT DURING HYDRAULIC DESCALING IN SPRAY OVERLAPPING AREA

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Abstract

Steel production is connected with high temperatures at which the steel reacts with oxygen in the surrounding atmosphere, creating scales on its surface. One of the most promising technologies for removing these scales when the steel is still very hot is hydraulic descaling. A row of high pressure flat jet water nozzles is usually used, with the feed pressure usually ranging between 10 and 40 MPa. The descaled material usually moves under the spraying nozzles. For most flat products, several nozzles arranged in a row must be used because the spray width of the nozzle is smaller than the width of the sprayed material. The steel surface where the scales are sprayed away by two adjacent nozzles is called the overlapping area. This area is dramatically overcooled during the typical configuration with an offset angle of 15° and an inclination angle of 15°. For this paper, both the typical and a new configuration with an offset angle of 0° were measured. Cooling homogeneity measurements were made to see the improvement in cooling homogeneity with the new configuration and spray impact pressure distribution measurements were made to see the size and shape of pressure distributions in the overlapping area for both configurations. Obtained results are presented and any improvement with the new configuration is discussed.

Keywords: steel, scales, hydraulic descaling, cooling, homogeneity

1. INTRODUCTION

During the production of hot rolled steel plates the semi-finished casting product (slab, bloom, ingot,..) is heated to a high temperature and fed into the rolling mill. At high temperatures, the material reacts with atmospheric oxygen and various types of oxides are formed. These oxides form a thin layer on the surface of the product and are called scales. Scales affect the quality of the rolled material and must be eliminated before the material enters rolling operations.

One of the most effective and widely-used technologies for removing these scales is hydraulic descaling. A row of high-pressure flat jet nozzles is used for descaling, and the feed pressure ranges from 10 to 40 MPa. In order to descale the entire width of the product, individual nozzles must overlapping along the direction of movement. The steel surface where the scales are sprayed away by two adjacent nozzles is called the overlapping area. The main objective of descaling is the elimination of all the scales on the surface of the product. Running counter to this is the requirement to maintain a temperature range during the full hot-rolling process; otherwise the operation could result in a less than desired quality of steel product. Cooling homogeneity along the width of the product during descaling is therefore important for the quality of the finished steel product.

The degree of overlapping depends on the system pressure, pitch between adjacent nozzles, their inclination angle and standoff. Study [1] states that the overlapping area must take less than 15 % of the spray width, otherwise the descaling becomes inefficient due to overcooling of the product. The overlaps also cause spray interference and reduce the effectiveness of the descaling. This could be a serious problem, for example, for electrical steels where the scales are very difficult to descale. The typical configuration of the descaling nozzles is with an offset angle of 15° and an inclination angle of 15°, which can cause this unnecessary overcooling. This paper compares this configuration with a new configuration which has a 0° offset angle and a 15° inclination angle and in which the water streams from adjacent nozzles collide. The goal of this paper is to show that the offset angle has a significant effect on the cooling homogeneity of the product.

1.1. Current state of the art

In recent years, development and new trends in high pressure water descaling have become more focused on smaller types of nozzles that are arranged closer to each other in a row. This allows manufacturers to decrease the distance between the nozzles and the steel product and makes descaling even more effective than before. This forces researchers to pay increased attention to heat loss during descaling. Studies which track this issue have been published for several years.

Heat loss is mainly a function of nozzle type, descaling time (velocity of the specimen), descalability of the scales and impact pressure [1]. It is not an easily-described or studied phenomenon. Articles [2] and [3] examine the heat loss from experiments and for the standardized velocity of the specimen, which is 1 m / s, and a wide variety of impact pressures. Article [2] deduces the heat transfer coefficient for impact pressures from 0.4 MPa up to 0.8 MPa from a series of experiments and estimates the values of the heat transfer coefficients in a range from 270 kW / m^2·K to 430 kW / m^2·K. Article [3] deduces the average heat transfer coefficient from a series of eight measurements and without any specification of the impact pressure in a range from 17.65 kW / m^2·K to 19.9 kW / m^2·K. Article [4] deals with this issue through a series of simulations for different settings of billet surface temperatures, nozzle export speeds and distances between the billet surface and nozzle and obtains the values of heat transfer coefficient within the range from 10 kW / m^2·K to 110 kW / m^2·K. This illustrates the variability of the outcomes from different research teams.

The intention of our laboratory research is not just to determine the heat transfer coefficient but also the reduction of the variability of heat loss along the width of the strip. The experiments described in this article focus primarily only on impact pressures and corresponding cooling homogeneity measurements.

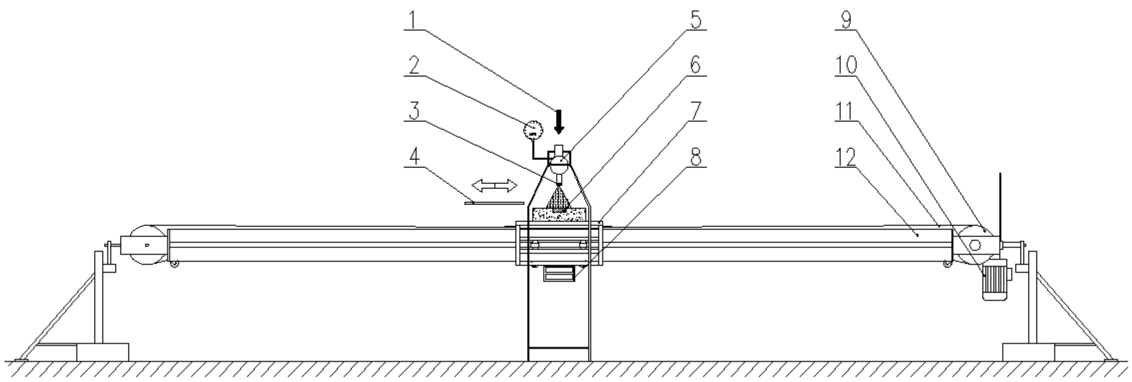

Fig. 1 Principal layout of the laboratory test bench: 1) cooling medium (water), 2) pressure gauge, 3) nozzle, 4) moving deflector, 5) nozzle manifold, 6) test plate, 7) moving trolley, 8) data logger, 9) roller, 10) electric motor, 11) hauling wire rope, 12) girder [5]

2. EXPERIMENTS SETTING AND LABORATORY EQUIPMENT

The experiments were performed for two settings of a pair of descaling nozzles. Both nozzles were of the same type, giving 58 l / min at 40 MPa and with a 45° spray angle. Tested configurations were as follows: 55 mm spray height, 43 mm nozzle pitch, 40 MPa water pressure, and 15° inclination angle. The first configuration had a 15° offset angle, and the second had a 0° offset angle (see **Fig. 2**). The tested specimen was a stainless steel plate with dimensions 320×300×25 mm, which was heated up to 900 °C.

The measurements of impact pressures distributions were made using a laboratory measuring device. The nozzle sprayed a moving plate which was equipped with a pressure sensor and the diameter of the sensor was 1 mm. For a given nozzle configuration, the pressure is measured as a position-dependent value while the plate with the sensor is slowly moving under the spraying nozzle.

Cooling homogeneity measurements were made on the laboratory test bench (see **Fig. 1**) by a line infrared scanner. The heated specimen moved at 0.5 m/s along the bench. The line infrared scanner scanned the surface temperature of the heated test plate 350 mm after the descaling section, i.e. 0.7 second after the descaling.

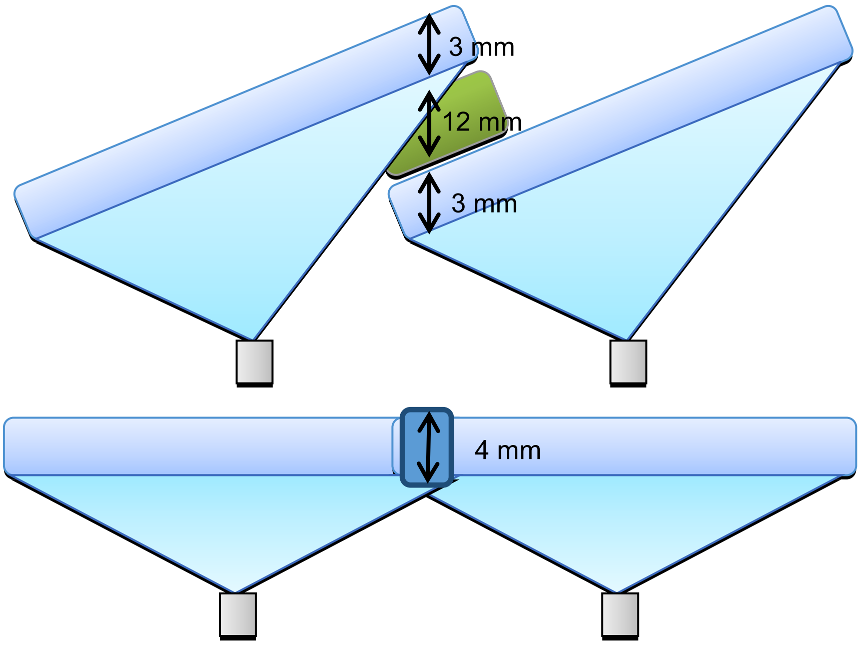

Fig. 2 The layout of spray nozzles.
The upper configuration is for a 15° offset angle and bottom one is for a 0° offset angle.

3. IMPACT MEASUREMENTS

The pressure distributions from both configurations were measured and a maximum value in a direction perpendicular to the width (the spray depth direction) was taken. The results are on **Fig. 3**. First configuration in red color shows the profile of the distribution from the left and right nozzle. It clearly illustrates the fact that due to the positive inclination angle the water from the right nozzle is reflected from the surface of the specimen and in the overlapping area causes interference with the water spray of the left nozzle. The reflected water from the right nozzle collides with the water from left nozzle just above the specimen in almost perpendicular angle and decrease the speed of the water from left nozzle in the direction of the spray. This interference is so significant that the impact pressure of the left nozzle is reduced to less than 50% in the overlapping area (see **Fig. 3**) and even affects a small part of the impact distribution that is outside of the overlapping area. In the second configuration, the water jets collide in a parallel fashion from both nozzles. This collision creates an increase in impact pressure in the overlapping area and forms a peak that is 2.5 times higher than the average impact pressure outside the overlapping area. The collision also increases the spray depth from 3 mm to approximately 4 mm.

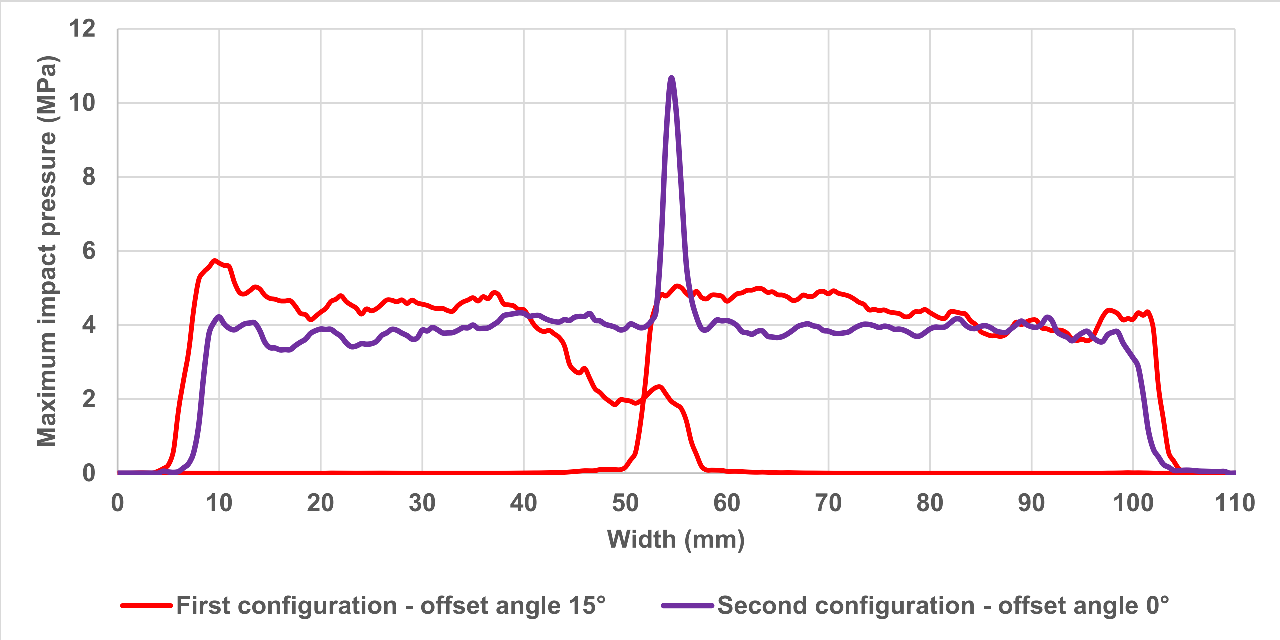

Fig. 3 Impact pressure measurements

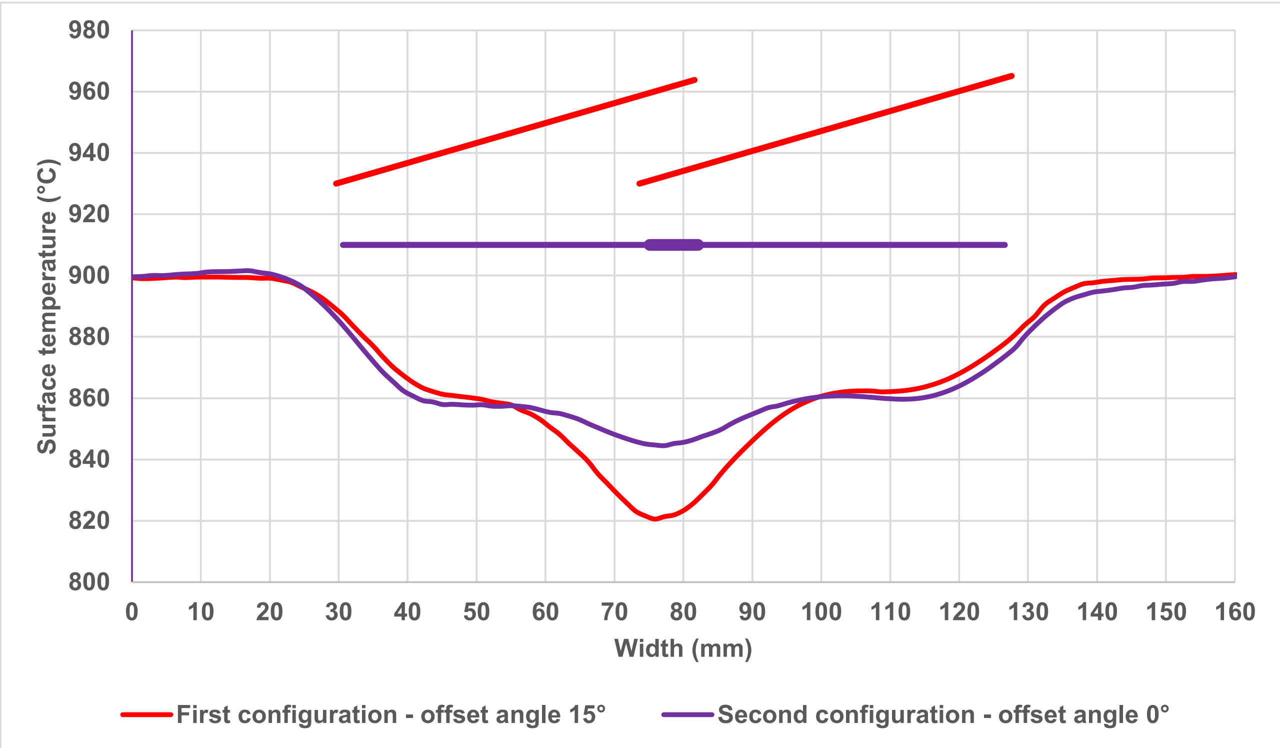

Fig. 4 Cooling homogeneity measurements with indicated corresponding configuration of the nozzles

4. COOLING HOMOGENEITY MEASUREMENTS

The cooling homogeneity measurements show the temperature distribution 0.7 seconds after the descaling section. The small size of the specimen caused unwanted heat loss on the border during the experiments.

The measured temperature distributions were additionally corrected and this undesirable effect was eliminated. The results presented in **Fig. 4** show the corrected temperature distributions.

Both experiments show a large decrease of the temperature field in the range where the nozzles sprayed. At the edge of the spray width outside the overlapping area the first experiment, indicated in red, clearly corresponds to the second experiment, indicated in purple. The biggest difference occurs right in the overlapping area in the middle of the spray width and in the vicinity of the overlapping area. The affected area is approximately 20 mm wide. The temperature difference in the peak for the first configuration, with respect to the area outside the overlapping area, reaches up to 38 °C, for the second configuration it reaches up to 14 °C, making the difference of the temperature between the first and the second configuration in this peak approximately 24 °C.

That said, it should be noted that sharp edges in the temperature profiles which develop immediately after the descaling operation are smoothed by the heat conduction, as the measurements were made 0.7 s after descaling, and also by the infrared camera, which has a measurement area of 10 mm. The temperature drop immediately after descaling is much more drastic than 0.7 s after the descaling, where the measurements were taken. The difference is partially blurred and the affected overlapping area increases. The impact measurements show that the affected area of the first configuration should not be greater than 15 mm, where approximately 9 mm is the actual spray overlapping area and 6 mm is so-called washout area, where the impact pressure of the left nozzle is still reduced by the water spraying out of the right nozzle.

5. DISCUSSION

The impact pressure measurements, together with cooling homogeneity measurements, show very interesting results. The evidence suggests that the relevant parameter affecting the intensity of cooling of the hot billet is the spray depth of the descaling section in the direction of movement rather than the magnitude of impact pressure. The spray depth of the descaling section in the overlapping area in the first configuration was approximately 18 mm (including the green area shown in **Fig. 2**); however, in case of the second configuration it was only 4 mm. This is illustrated in **Fig. 2**.

In the case of the first configuration the descaling section in the direction of movement in overlapping area can be split into three main parts as shown in **Fig. 2**. This includes two sections (blue) where the water directly impacts the surface of the specimen and a third middle section (green) where the water moves along the surface. The blue sections each have a depth of 3 mm each and the middle section is approximately 12 mm wide. What is happening in this section is that water from the right nozzle moves in the overlapping area through the green section, which contributes to significant heat loss in this area and collides with the water from the left nozzle. The collision slows down the water stream and intensifies the cooling in the green middle section. The heat transfer coefficient in this area increases as the water is trapped between the sprays and partially evaporates at the heated plate. Due to the greater depth of this area the intense cooling lasts longer. Unfortunately, the intense cooling of the specimen forgoes the main descaling operation in the overlapping area, which is ensured by the unaffected left part of the right nozzle. Such an effect of precooling before descaling might cause a significant change of the physical characteristics of the scales and could reduce the descalability of the scales due to the reduction of the temperature of the surface and scales.

In the case of the second configuration, a short intensive cooling impulse leads to higher heat loss in the overlapping area, yet doubling the impact pressure in this area does not mean doubling the heat flux. This statement is also supported by article [2], where it was shown that the heat transfer coefficient depends linearly on impact pressure but with a nonzero constant regression coefficient. The higher heat loss is reflected in the temperature drop in the middle section of the cooling homogeneity measurement. The depth of the descaling section is small, almost no precooling occurs and it is more likely that the thermal shock is developed and contributes to better descaling of the scales.

CONCLUSION

This research paper has shown that cooling homogeneity during descaling operations of hot rolled products in the spray overlapping area might depend on the depth of the descaling section in the direction of movement rather than on the impact pressure from the sprays. For the current presented configurations, the results imply that the bigger the depth of the descaling section in the overlapping area is, the greater the variability of the temperature along the strip. This suggests that the currently widely-used nozzle configuration is not optimal from a cooling point of view. Together, these results provide important insights into the descaling process and reveal a new perspective in the issue of descaling optimization. The current study was limited by the absence of any measurements from the thermocouples and determination of the heat transfer coefficient. Yet it seems that this study was beneficial and further research should be conducted to determine the heat transfer coefficients in the overlapping area and corresponding surface temperatures right under the descaling section.

ACKNOWLEDGEMENTS

"This work is an output of research and scientific activities of the project LO1202 with financial support of the MEYS under the programme NPU I"

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