

MUTUAL COLLISION OF WATER JETS FROM ADJACENT HIGH PRESSURE FLAT JET NOZZLES ON FLAT SURFACES DURING HYDRAULIC DESCALING

Michal Pohanka, Miroslav Raudenský, Jong Yeon Hwang, Jong Woo You, Sang Hyeon Lee

Original scientific paper

High energetic water jets sprayed from nozzles are used for scale removal. Special nozzles with flat and very narrow jets for high feed pressure are used. This process, called descaling, is used in hot rolling, for example. A number of jets must be used to cover the total width of a rolled strip. High quality and homogeneity of the descaling process is required. A row of high pressure descaling nozzles is often used. This paper focuses on the area where water streams from adjacent nozzles interact. Water impact measurements were taken for several nozzle configurations and the measuring technique with the results obtained is presented. The water impact pressure for multiple nozzles was computed and the results were compared to the measurements.

Keywords: descaling; interaction; jet; nozzle; measurement; stream

Uzajamna kolizija vodenih mlazova iz susjednih mlaznica s plosnatim mlazom visokog tlaka na ravnoj površini tijekom hidrauličnog skidanja kamenca

Izvorni znanstveni članak

Vrlo snažni vodeni mlazovi iz mlaznica rabe se za skidanje kamenca. Koriste se specijalne mlaznice s plosnatim i vrlo uskim mlazom za stvaranje vrlo visokog tlaka. Taj postupak, nazvan skidanje kamenca, primjenjuje se, na primjer, kod valjanja na toplo. Mora postojati veliki broj mlazova kako bi pokrio cijelu širinu valjanog traka. Potrebna je visoka kvaliteta i homogenost postupka skidanja kamenca. Često se rabi niz mlaznica visokog tlaka za čišćenje kamenca. Rad je usmjeren na područje u kojem uzajamno djeluju vodeni mlazovi iz susjednih mlaznica. Izmjereni su udari vode iz mlaznica s nekoliko konfiguracija i raznih metoda mjerenja i daju se dobiveni rezultati. Izračunat je tlak udara vode iz mnogih mlaznica te su rezultati uspoređeni s mjerenjima.

Ključne riječi: interakcija; tok; mjerenje; mlaz; mlaznica; skidanje (čišćenje) kamenca

1 Introduction

Continuous production of steel products in rolling mills is currently the main method of steel treatment. In hot rolling mills, the steel is heated up to 1250°C in slab furnaces. This procedure reduces deformation forces for rolling but creates a problem with oxide creation on the surface. The hot surface is exposed to the surrounding atmosphere and the ferrite interacts with oxygen to form FeO (wüstite), Fe₂O₃ (hematite), and Fe₃O₄ (magnetite) oxides, collectively called scales [1]. These scales can significantly reduce the surface quality of the final product. The scales must be removed prior to the rolling process to improve the product's surface quality and to prolong work roll life [2]. One very efficient method for effective scale removal is a hydraulic descaling method which uses high-pressure descaling nozzles [3]. The typical feed water pressure for these nozzles ranges from 10 MPa up to 40 MPa. Descaling nozzles are designed so that they can form a very flat and highly kinetic water jet which is used as a water knife. To cover the entire width of the product the nozzles are arranged in a row and the water jets must overlap.

Usage of descaling nozzles also carries problems with under-cooling and descaling homogeneity across the product width. Using large descaling nozzles causes very intense cooling with a heat flux of over 20 MW, which is in most cases objectionable. This behaviour is inconsistent with the demand for maximum descaling effect [4]. This overcooling effect is even more significant in the area where water streams overlap from two adjacent nozzles. These results in unwanted overcooled lines which are often called tiger stripes. Little information can be found in literature about the collision

of water jets. Oyakawa studied flow and heat transfer when four solid jet nozzles were sprayed on a flat surface [5], Slayzak studied the interaction between adjacent free surface planar jets on local heat transfer [6], Hardalupas studied the interaction between sprays from multiple coaxial airblast atomizers [7], De Cock modelled the distribution of agricultural sprays [8], and two more papers deal with heat transfer during cooling with multiple nozzles [9, 10]. No publication addressing the mutual collision of water jets from high pressure flat jet nozzles was found.

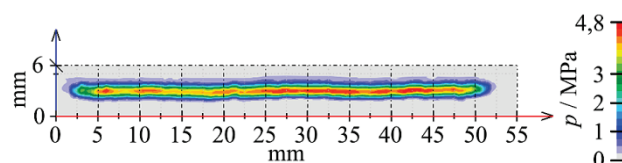


Figure 1 Experiment E1 – whole foot print of spray impact from single (left) nozzle

In order to improve the homogeneity of the descaling process, a new configuration for the descaling nozzles is suggested so that a uniform water knife across the whole width of the product is formed. The water stream from descaling nozzles produces impact pressure on the surface of the product. An example of such a footprint for a single nozzle is shown in Fig. 1. Our goal was to create this sort of uniform line for the entire width of the descaled product using multiple nozzles arranged in one row. The unknown parameter was nozzle pitch for a given spray height. The water jet from flat jet descaling nozzles is not a solid water stream but one which decays into droplets and small clusters of droplets [1]. An example of this water jet structure is shown in Fig. 2, which was taken by

camera while the water stream was flashed with a very intense and short duration laser beam. It is obvious that the water stream is neither a solid water stream nor single droplets.

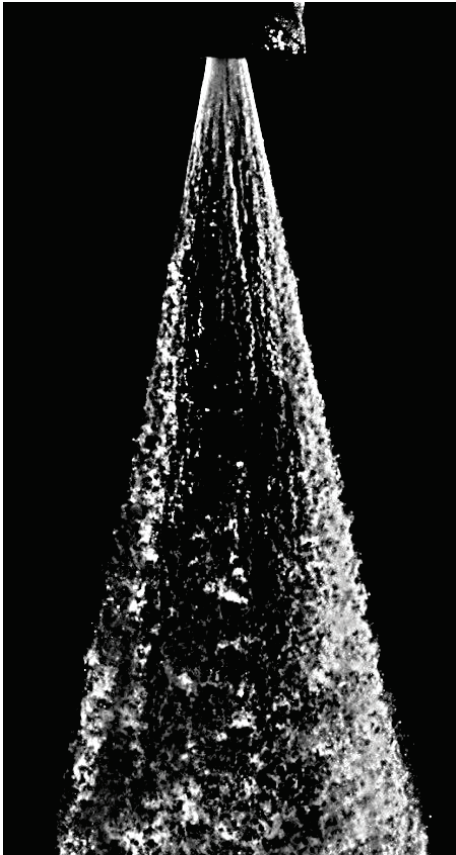


Figure 2 Water stream structure of descaling nozzle at 20 MPa. The length of stream is 100 mm

The mechanical effect of high-pressure descaling nozzles can be explored through measurements of impact pressures of the nozzle as well as through erosion tests on aluminium plates and by investigating the abrasive effects of the stream. The measurements of the abrasive effect of the water jet are described in detail in [12÷14]. The aim of this paper was to focus on impact measurements of the water jets and to analyse the outcomes of experiments in order to find the appropriate nozzle pitch and to compare measured results to the computed ones.

2 Measurements

Two descaling nozzles of the same type were used to study the overlap area. Everloy DNM04835SPF 1 nozzles with water flow stabilizers were used. The applied feed pressure was 40MPa. The water flow rate was 0,96 l/s and the nominal spray angle was 45°. The distance of the nozzle from the sprayed surface was set to 55 mm; however, the spray distance was 57 mm due to the nonzero inclination angle that was set up to 15° (see Fig. 3). Two descaling nozzles were arranged in one row (see Fig.4). Five measurements were taken in total (see Tab. 1). The first two measurements were taken with only one spray nozzle to see the impact forces on a flat surface not disturbed by any adjacent nozzles. Next, three

experiments were performed with both nozzles for various nozzle pitches to study the overlap area.

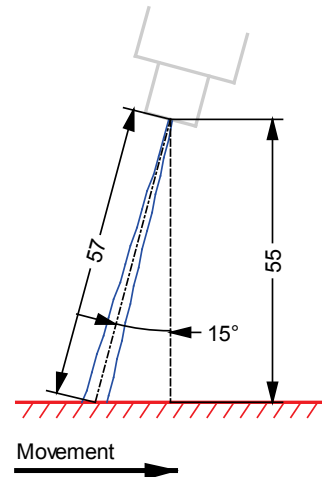


Figure 3 Side view of spraying nozzle

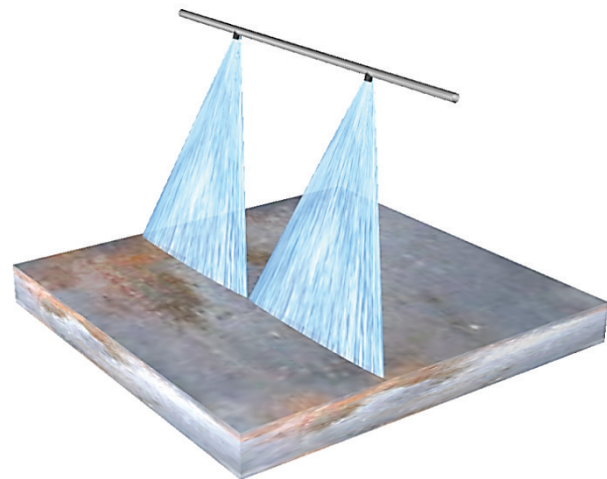


Figure 4 Nozzle configuration

Table 1 Experiment plan

Experiment	Pitch / mm	Height / mm	Pressure / MPa	Offset / °	Inclination / °
E1-left	-	55	40	0	15
E2-right	-	55	40	0	15
E3	43	55	40	0	15
E4	49	55	40	0	15
E5	51	55	40	0	15

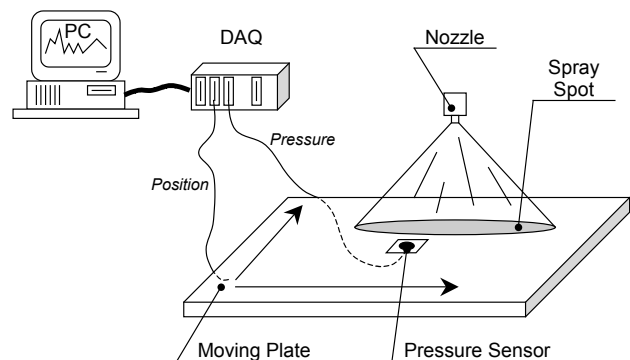


Figure 5 Schematic diagram of experimental set-up

During the experiments the water was sprayed onto a flat surface. The flat plate was equipped with pressure

sensor. The diameter of active area, which measured the pressure, was 1 mm. The flat plate with pressure sensor was placed on the X - Y positioning system which was connected to a computer along with the pressure sensor (see Fig. 5). The computer controlled movement of the flat surface while the nozzles sprayed it. The computer also recorded the actual value of measured pressure and stored the pressure as a position dependent value. The recorded values of the measured pressures under a single spray nozzle are displayed as impact forces in Fig. 1.

For nozzles with a very narrow spray spot and for a small distance of any nozzle from the moving flat surface, the measured data does not represent a real pressure distribution. The values are averaged over the active area of the pressure sensor and correction of the measured distribution should be considered. To correct the measured data, a Fourier transform can be used as described by [15].

3 Results

Impact forces of single sprays were measured first (experiments E1 and E2). The entire impact distribution for the left nozzle is shown in Fig. 1. Edges of the impact area (the area of our interest) for both nozzles were measured with higher resolution. The obtained results are shown in Fig. 6 and Fig. 10 for the left and right nozzle, respectively.

To find the correct nozzle pitch the measured 2D distributions were simplified into two curves (one for experiment E1 and the second for experiment E2). One average value was computed from the values in the depth direction (vertical axis in Fig. 6 and Fig. 10) for each slice perpendicular to the width direction (horizontal axis) and a curve was created from these points. The computed curves are shown in Fig. 6 and are labelled as E1 and E2. The optimum nozzle pitch was computed using these curves by moving data from experiment E2 in the width direction (horizontal axis in Fig. 6 and Fig. 10). This data was summed with data from experiment E1 and the result for the optimum nozzle pitch of 49 mm is shown in Fig. 7 as E1+E2. It is obvious that the computed average pressure is almost constant.

Experiment E4 was performed with the computed optimum nozzle pitch of 49 mm to see the actual pressure distribution. The obtained result is shown in Fig. 12. There is a red spot in the overlap area where the water streams from adjacent nozzles hit each other. The result of that collision is an increased impact force in that area. The average pressure curve was computed from measured data for experiment E4 and the obtained result is compared with predicted values in Fig. 7 (compare E4 and E1+E2). The average pressure computed from experiment E4 is higher by 45 % than the values predicted from E1+E2 in the overlap area.

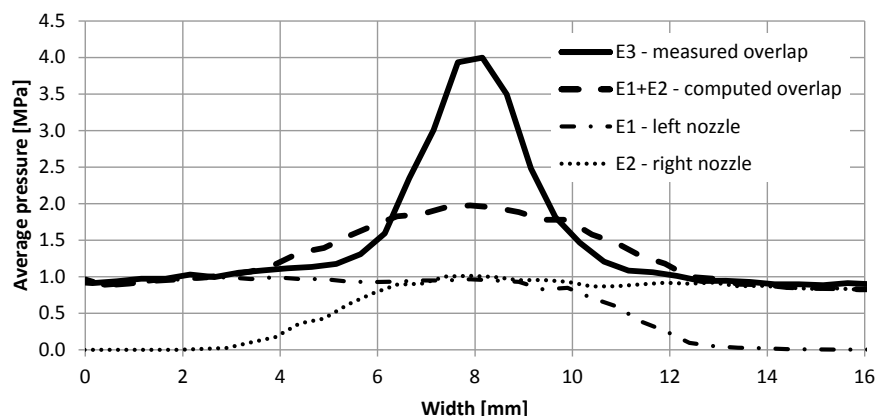


Figure 6 Experiment E3 – comparison of measured and computed pressure distribution for nozzle pitch 43 mm

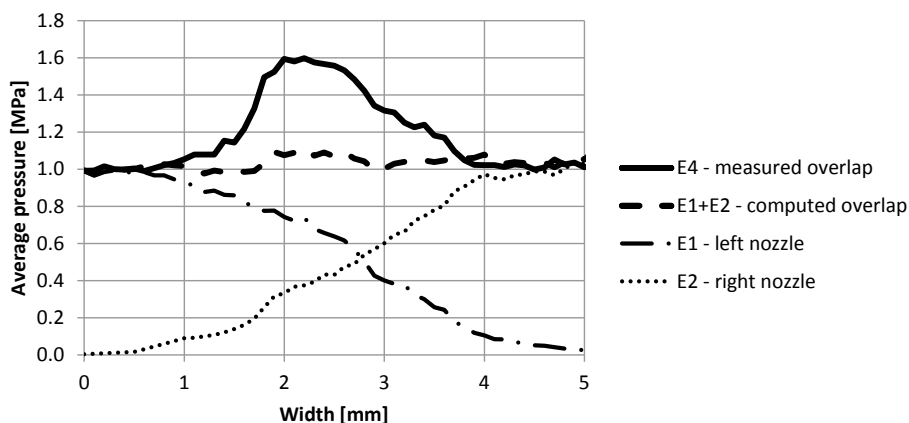


Figure 7 Experiment E4 – comparison of measured and computed pressure distribution for nozzle pitch 49 mm

To see what happens when water streams overlap too much, experiment E3 with a nozzle pitch of 43 mm was performed. In that case there is about a 4 mm overlap area

where the average pressure is over 80 % of its maximum for both the left (E1) and right (E2) nozzles (position 6-10 mm in Fig. 6). The measured impact distribution is shown

in Fig. 11. The depth of the spray pattern is much greater in the overlap area. The pattern is two times bigger in the depth direction for values which are above 25 % of the maximum value. The computed average pressure from experiment E3 (see Fig. 6) is even four times higher than in the non-overlap area.

The final measurement was taken for a nozzle pitch of 51 mm. The overlap area was very small for this case

(see Fig. 8). The average pressure curve computed from experiment E5 was compared to predicted values (E1+E2). The average pressure computed from experiment E5 was higher by about 50 % than those values computed from E1+E2 in the overlap area. The percentage increase is very similar to the value obtained from experiment E4.

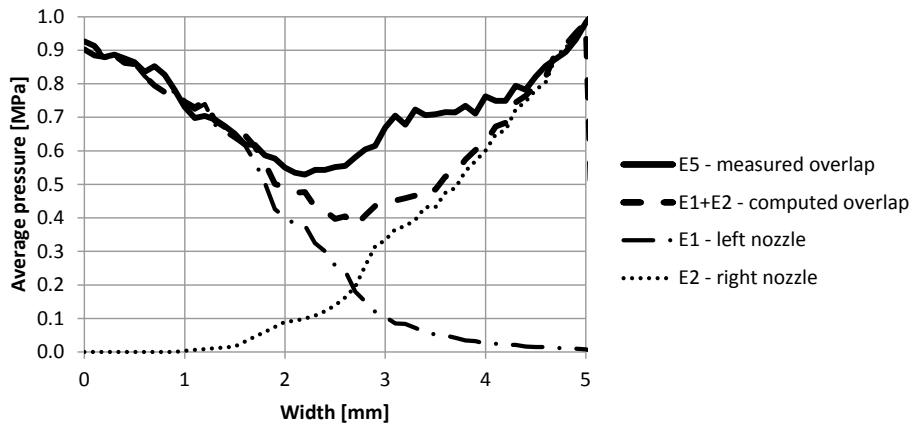


Figure 8 Experiment E5 – comparison of measured and computed pressure distribution for nozzle pitch 51 mm

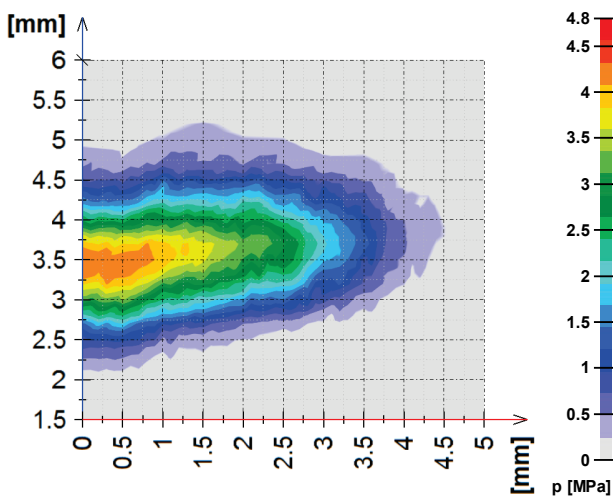


Figure 9 Experiment E1 – detail of spray impact from left nozzle

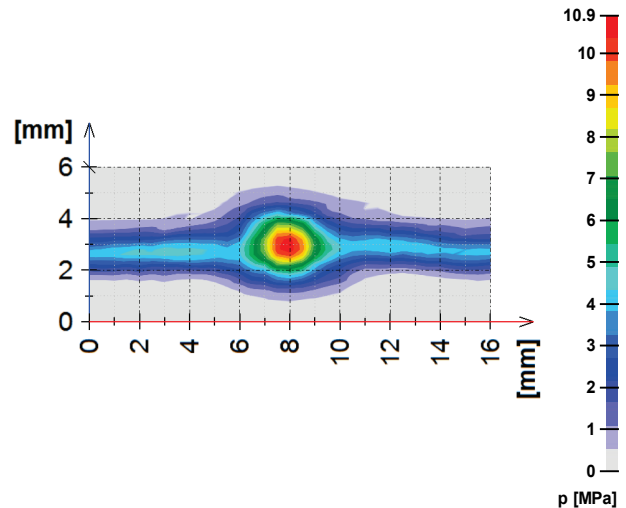


Figure 11 Experiment E3 – detail of overlap area for nozzle pitch 43 mm

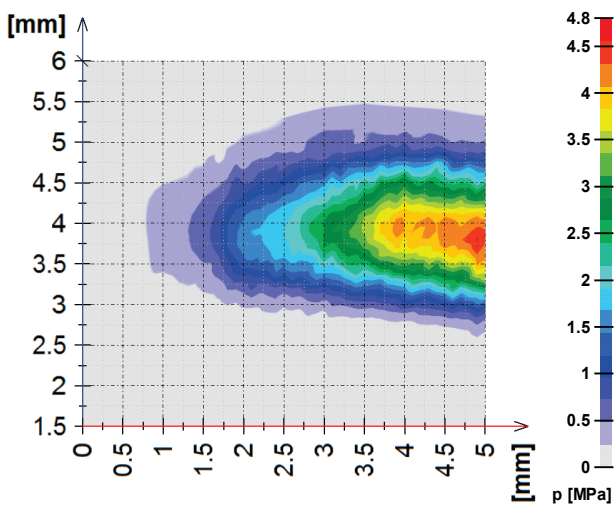


Figure 10 Experiment E2 – detail of spray impact from right nozzle

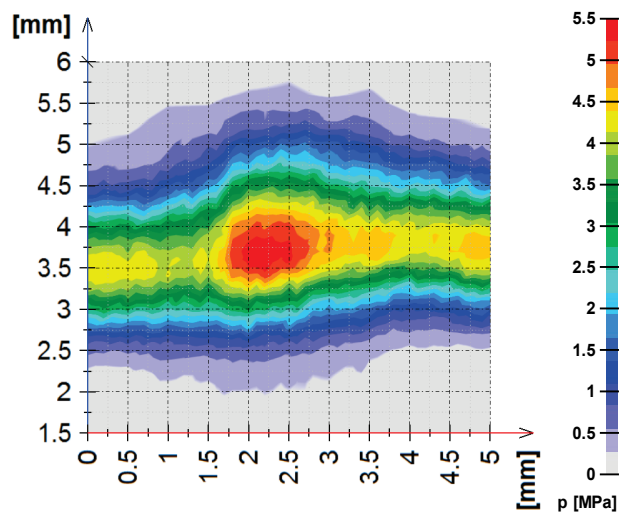


Figure 12 Experiment E4 – detail of overlap area for nozzle pitch 49 mm

4 Conclusion

The mutual collision of water streams from two adjacent high pressure descaling nozzles was studied experimentally. A special device for measuring impact forces on flat surfaces was described. A nozzle pitch of 49 mm was suggested from impact measurements of a water stream from a single nozzle. It was found that for the actual overlap area the average pressure is about 50 % higher than the one computed from single nozzle measurements when the overlap area is small. For cases where the overlap is large, the average pressure in the real overlap can reach 200 % of the value computed from a single nozzle measurement, which is 400 % of the value for a single nozzle. The photo of the water stream showed a very complex structure consisting of small droplets and also of relatively large clusters of water. It is neither a solid stream nor small droplets. The water from adjacent nozzles is partially interacting before the water impacts the sprayed surface. The disagreement between measurement and prediction depends mainly on the density of the spray (water/air ratio) and the size of the overlap. When water density increases, the difference between calculation and measurement also increases. This is due to the higher probability that the water droplets from one spray contacts water droplets from the second spray. When this happens the water is splashed in the depth direction and also toward the plate. This results in a greater spray depth (vertical axis in Fig. 11) and more narrow overlap area than the computed one.

An advanced two-faze simulation should be used to predict impact distribution and the computed values should be compared with measured ones. Simple computation of the overlap area is not possible from a single nozzle measurement and the error increases when the overlap is increased.

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5 References

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