# DESIGN OF COOLING SYSTEMS FOR GROOVED ROLLS

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**Abstract**

This article deals with the design of cooling systems for grooved rolls. The purpose is to extend the life of rolls by minimizing negative thermal stress during the rolling process. Specifically, this paper presents a design for a cooling section for a U-caliber roll. This article first describes an experimental stand which was built to obtain the boundary conditions (Heat Transfer Coefficients) on the surface of rolls. The laboratory stand consisted of a rotary cylinder and a cooling section. A set of thermocouples was installed in the cylinder. HTCs are evaluated from the temperature record from the cooling experiments, and used to solve a 2D inverse heat conduction problem.

The influence of water pressure and various geometric configurations on cooling intensity were studied.

The second part of this article deals with the design of an optimal cooling configuration to reduce thermal stress in critical points of the grooved roll. The temperature-deformation FEM model was used to express the state of stress inside the roll. The HTCs obtained from the first part were used as boundary conditions.

The cooling effect of the proposed cooling configuration was verified experimentally. A stainless steel sample with U-shaped groove and instruments was made for this purpose. The size and dimension of the sample was designed on a realistic caliber scale.

**Keywords:** Design of cooling system, grooved role, thermal stress

## 1. INTRODUCTION

Water jet cooling of steel rolls is commonly used in industrial applications. One typical example is the cooling of rolls for hot rolling [1]. Optimal cooling [2] is important, as it prolongs the life of work rolls. Cooling optimization can be achieved under laboratory conditions. During such experiments, the heat transfer coefficient is measured, [3, 4] and used for numerical simulations. The heat transfer coefficient (HTC) changes quickly during hot rolling and evaluating the boundary conditions often requires advanced inverse computation [5].

HTCs are obtained from the cooling temperature record. Since taking measurements during industrial operations is complicated, expensive and in many cases impossible, it was necessary to take measurements in the laboratory while simulating operating conditions during cooling. An experimental stand able to measure temperatures during cooling with different speeds of rotation, temperature ranges, coolant pressures, and nozzle types, number and arrangement were built.

This experimental device was used to obtain the temperature record for several nozzle configurations, which could then be used for grooved roll cooling. This data was used as inputs for the inverse heat conduction problem to obtain the cooling intensity (HTC) [6].

## 2. LABORATORY STAND

The experimental roll was equipped with several thermal sensors connected to a data logger in a test segment (see **Figure 1**). The measurement procedure consisted of 4 steps:

- The test segment was heated to the starting temperature

- The heater was removed and the roll was covered with a deflector
- The speed of the roll and water pressure were set
- The deflector was opened and experiment was started

The temperature records were evaluated using the inverse heat conduction problem (IHCP). A detailed description appears in the references [8].

**Figure 1** Laboratory experimental roll

## 3. INFLUENCE OF WATER PRESSURE ON HTC

A configuration with four nozzles was used (see **Figure 2**). Each nozzle was placed 100 mm away from the surface (perpendicular to the surface). The peripheral velocity of the roll was 1 m/s. Four levels of water pressure were tested (2, 5, 8, 12 bar). Water distributions along the width of the roll are shown in **Figure 2**.

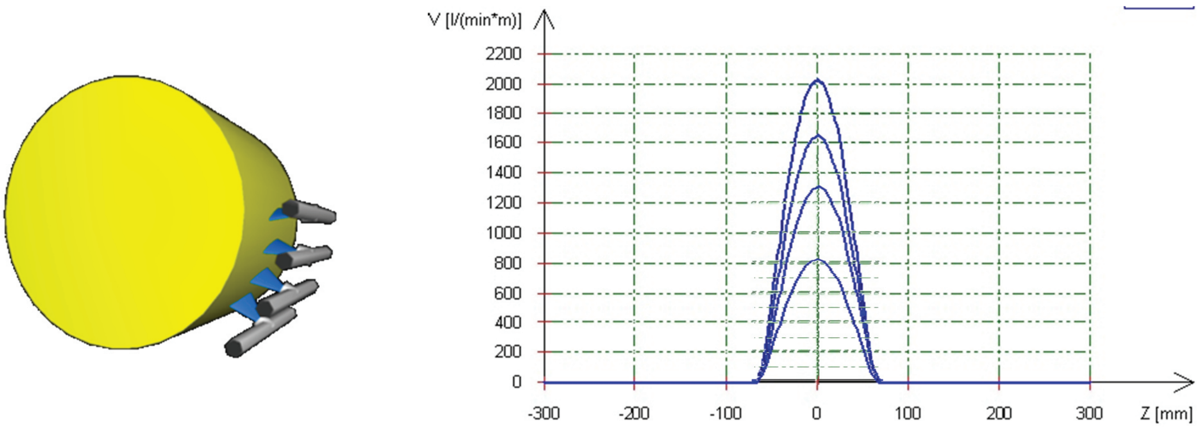



**Figure 2** Nozzle configuration with experimental roll (left). Water distribution along the width of the roll (right)

Maximal HTC value at the center of the nozzles and average HTC values for the entire cooling zone are plotted in **Figure 3**.

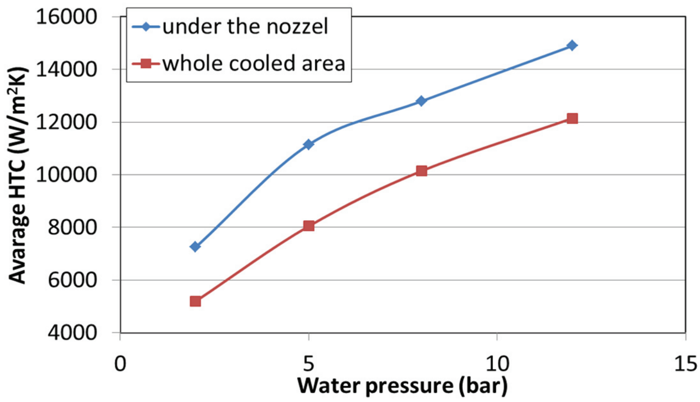



**Figure 3** HTC dependent on water pressure

## 4. INFLUENCE OF NOZZLE POSITION ON HTC

Three different nozzle positions were tested. Four nozzles oriented perpendicularly to the surface were used in each setup. The 100 mm distance from surface was also maintained in each test. The angles between neighboring nozzles were adjusted for each test (see **Figure 4**). Water pressure was 5 bar and the peripheral velocity of the roll was 1 m/s.

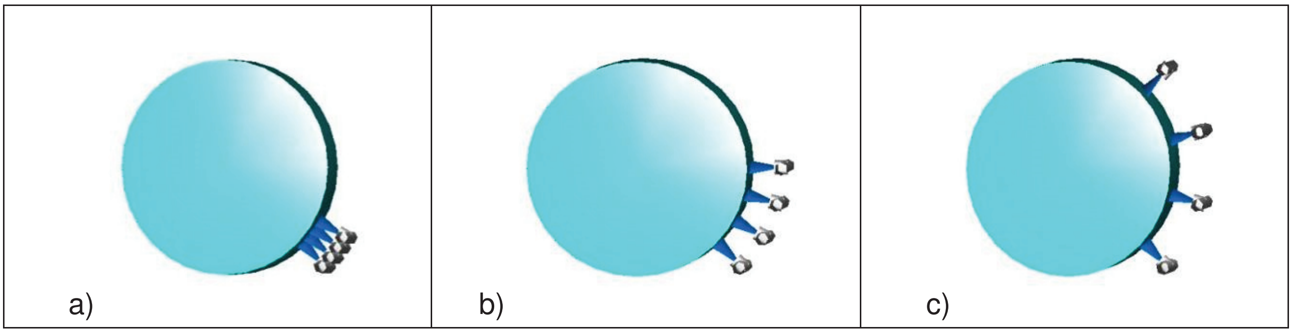



**Figure 4** Nozzle configuration angles between neighboring nozzles a = 7°, b = 15°, c = 30°

The highest HTC value was achieved for the smallest angle, 7° (case A). In contrast, the largest influence area by cooling was for the largest angle, 30° (case C). The cooling effectiveness was compared using the average HTC value for the same sized area for all three cases (see **Figure 5**). The average values at the center of the nozzles are also shown in **Figure 5**.

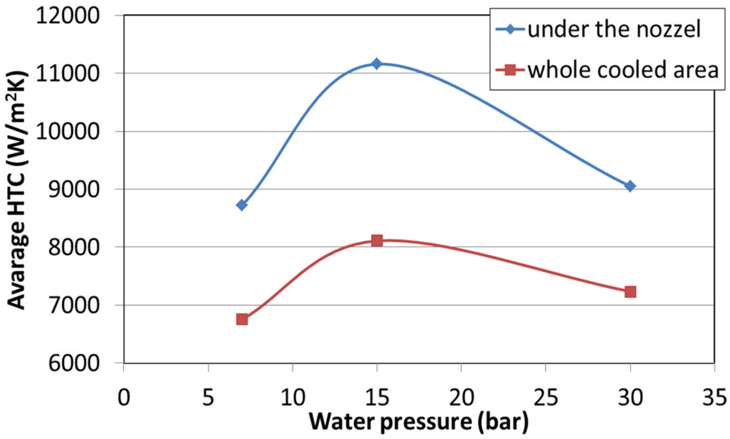



**Figure 5** Average HTC values dependent on angle between nozzles

## 5. DESIGN OF COOLING SYSTEM FOR GROOVED ROLL

The measured cooling intensities for various configurations, shown in the previous chapter, were used as boundary conditions for the thermal-deformation model of a grooved roll (**Figure 6**). The model was built in ANSYS and it was used for sensitivity analysis of the stress state. Several types of cooling sections were simulated using this ANSYS model. Temperature and stress in the critical point of the roll were observed for ten simulated rolling cycles, for each case of cooling.

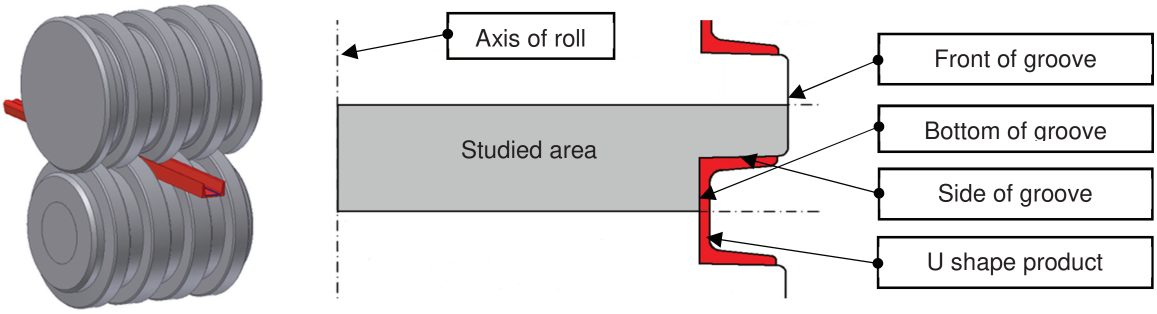



**Figure 6** Grooved roll

Several cooling configurations were tested, and two are shown in this article. The first case focused on the intense cooling of the bottom of the groove. The side wall was cooled at low intensity and the front of the roll was not water-cooled. The second case focused on the intense cooling of the side and front of the groove. The bottom section was cooled at low intensity. The comparison of temperature distributions inside the roll after ten rolling cycles is shown in **Figure 7**. Temperature development at several points during rolling is shown in **Figure 8**. Stress at the critical point (corner) was computed for both cases (see **Table 1**).

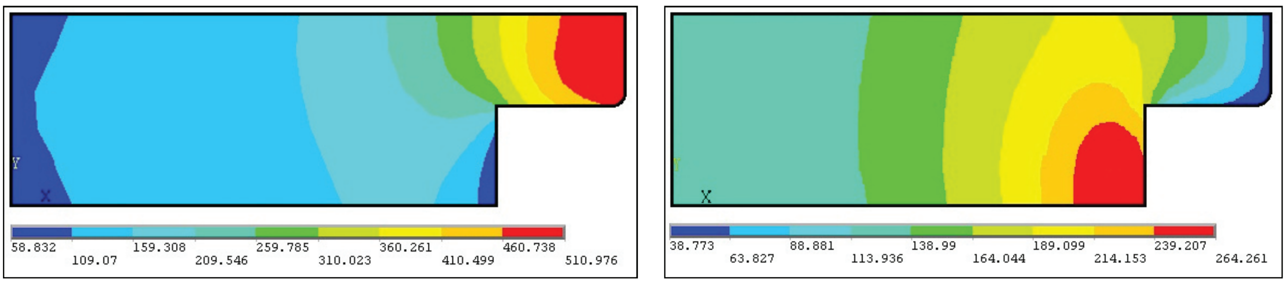



**Figure 7** The temperature distribution (°C) inside the roll after ten rolling cycles (left - case 1, right - case 2)

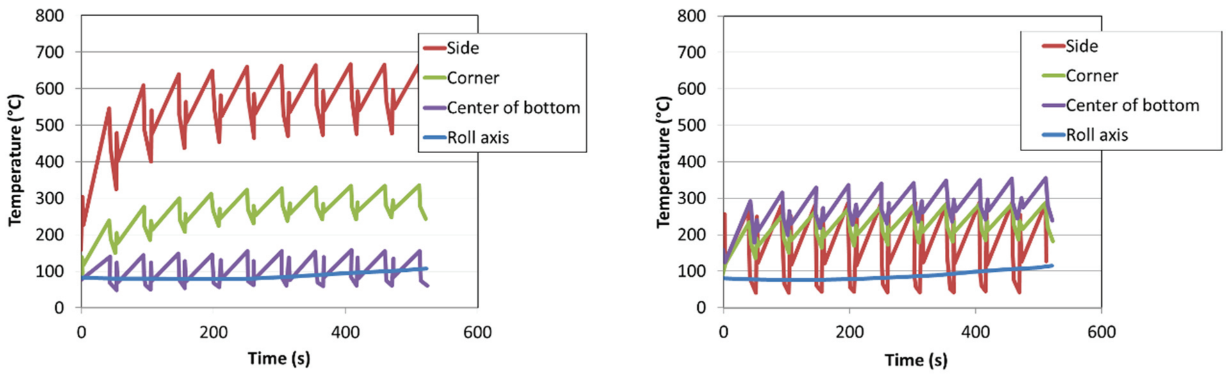



**Figure 8** Temperature development during the rolling (left - case 1, right - case 2)

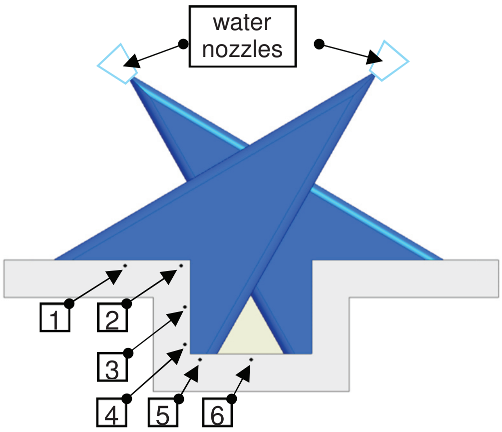
**Table 1** Radial stress (MPa) in the corner after 10 rolling cycles

| | **Case1** | **Case 2** |
|---|---|---|
| Max. radial stress | 570 | 0 |
| Amplitude of radial stress | 640 | 850 |

The stress state in case 1 was predominantly tensile stress, in contrast to the second case, where the stress shifted only to compressive stress. The second case was more favorable, even though the amplitude of radial stress increased because tensile stress has a negative impact on forming surface cracks and the lifespan of the roll.

## 6. VERIFICATION

The cooling intensity for the best cooling case (according to the numerical model) was tested again and verified. A model of one section of a grooved roll was made from austenitic steel. The sample was equipped with six thermocouples (see **Figure 9**) in order to determine the cooling distribution on the surface. The measured temperatures from the experiments were used as inputs for the inverse heat conduction problem. The HTC on the surface was obtained by solving this inverse problem.



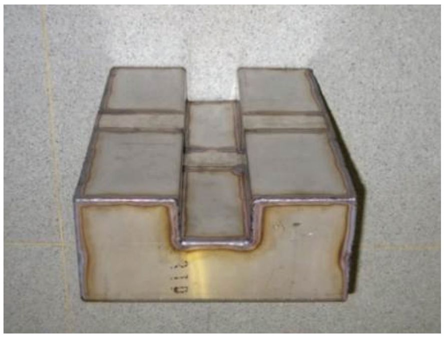



**Figure 9** Model of one section of a grooved roll.
Cross section with thermocouple positions (left) and photo (right)

## 7. CONCLUSION

The first experimental procedure investigated the influence of water pressure and nozzle positions, and the results show that cooling intensity increases with increasing water pressure. The dependence is not linear; the saturation of cooling intensity was observed.

The influence of nozzle position on the HTC is shown in **Figure 5**. The cooling intensity may be significantly increased by changes in the positions of the nozzles around the roll. An optimal angle of 15° for this case was found.

Real boundary conditions (HTC) from the first experimental procedure were used in the simulation step of this work. The FEM model was used to simulate the temperature and stress-strain analyses during the rolling process. Numerical simulation was used to optimize the design of the cooling section.

A new cooling nozzle configuration was proposed to reduce negative thermal stress (tension) in critical areas of the grooved roll and thus increase the lifetime of these rolls.

## ACKNOWLEDGEMENTS

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