COLD ROLLING - COOLING ENHANCEMENT AND OPTIMIZATION

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Abstract

The paper is focused on experimental research with the goal of enhancing cold mill capability by improving the currently used coolant setting (various types of emulsions) and cooling configuration (type of nozzle, nozzle position, distance and inclination angle of headers with respect to the roll).

The experimental research was divided into two phases. The initial phase examined the impact of various emulsion types on cooling intensity. Pure water, coconut, lard and palm oil-based emulsions with various oil concentrations were tested. The highest cooling intensity was found for the pure water. The heat transfer coefficient decreased with the increase of the oil concentration. The cooling intensity was comparable for different emulsions.

The second phase was focused on cooling optimization. The goal was to enhance cooling intensity while reducing the consumption of the cooling medium. The research methodology was based on the specialized experimental stand that simulated cooling processes on a rotating surface. The heat transfer coefficient was investigated for a typical cooling system. Then, the cooling configuration (nozzle size, type, position and header inclination angle) was optimized and the comparison of a new and old cooling system shoved higher cooling efficiency with lower water consumption (25 % less).

Finally, roll cooling simulations were conducted for both cooling variants to compare the impact on roll temperature during rolling. The advantage of the optimized cooling system was minimal (roll temperature decreased by 5°C) due to the slight difference between the coolant temperature (60°C) and the strip temperature (200°C). However, lowering the coolant temperature to 20°C caused the roll temperature decrease by 30°C.

Keywords: Cold rolling cooling; emulsion concentration; cooling intensity, heat transfer coefficient, cooling optimization

1. INTRODUCTION

Increasing the capability of a cold rolling mill, together with energy savings, is a challenging topic. Work roll cooling process optimization could benefit by increasing strip thickness reduction per stand and rolling speed. The problem is in enormous heat generation in the roll bite that causes scratches on the strip surface. Efficient (optimized) cooling can extract the heat from the work roll body.

Emulsions are used for cooling and lubrication. The cooling efficiency decreases with the increase in oil concentration [1]. Other studies [2] - [8] demonstrate the possibility of cooling enhancement by adding additives such as nanoparticles, polymers, or surfactants into an emulsion. This research first focused on various types of emulsions and oil concentrations. Emulsions were based on coconut, lard, and palm oil. The heat transfer coefficients were compared with the reference experimental medium – pure water (chapter 3.1).

Cooling efficiency could also be increased by optimization of a spray pattern. The heat transfer coefficient was investigated for the reference cooling configuration (current situation). Then, the cooling geometry together with nozzle size and type was optimized by studying the influence of several parameters (nozzle type, spray configuration, fluid pressure, etc.) on a heat transfer coefficient (chapter 3.2). The cooling effectiveness of a new system was compared with the actual situation by cooling simulations (chapter 3.3).

2. EXPERIMENTAL DEVICES AND PROCEDURE

The research was divided into two phases. The first was to study the effect of various emulsion types and concentrations on the cooling intensity. A static experimental stand (**Figure 1** on the left side) was used for the study. A k-type thermocouple (ø 0.5mm) was inserted into the grove made by electro-erosive machining of the stainless steel body, and it was soldered by silver. The distance between the sprayed surface and the measurement point was obtained by calibration. It was 0.4 mm. The stainless steel sensor (Ø 20mm) was inserted into the peek insulation and metal body. This sensor was heated up by the electrical heater to the initial temperature of 300°C. Experimental nozzle Lechler 460.604 was positioned in the chamber and oriented to spray up. It was connected to the water pump and water pressure was controlled by the manometer. Once the coolant pressure was set (5 bar), the heated sensor was positioned on the top of the chamber, facing down. A water deflector positioned between the nozzle and the sensor was opened when all the experimental parameters (coolant pressure, sensor temperature, etc.) were set. The coolant was sprayed on the sensor surface until it reached a temperature lower than 70°C (the coolant temperature was 60°C). Temperatures were measured with a frequency of 320 Hz, and surface temperature, heat transfer coefficient, and heat flux were computed using the inverse method [9].

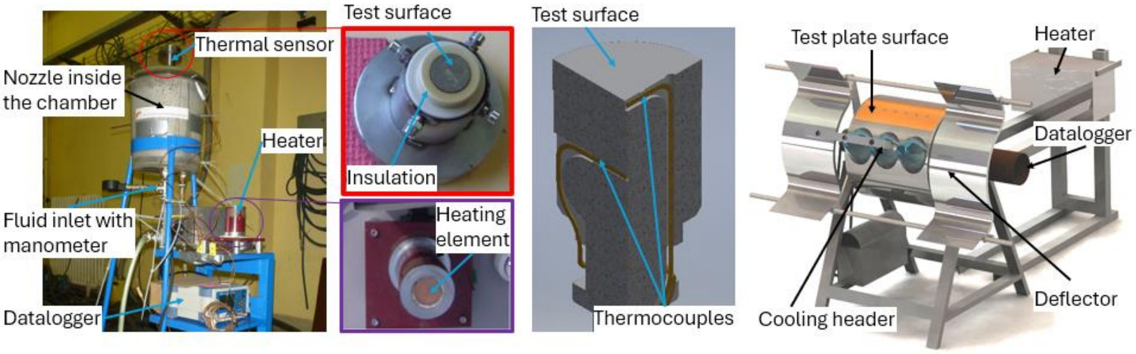

Figure 1 Static experimental stand (on the left), the thermal sensor (in the center, red rectangle), heater (in the center, purple rectangle) and cross-section of the thermal sensor with the thermocouples, dynamic testing device (Roll) on the right side.

The second experimental equipment (Roll, **Figure 1** on the right side**Chyba! Nenalezen zdroj odkazů.**) was d eveloped by the Heat transfer and fluid flow laboratory (HeatLab) to experimentally simulate a heat transfer on rotating surfaces. It is composed of a roll with a diameter of 650 mm. The experimental plate was made of stainless steel with dimensions of 500 x 320 x 25 mm. The plate was embedded by 7 thermal sensors positioned in a horizontal line with a spacing of 50 mm. Thermocouples type K (ø 0.5mm) were used and the measurement point was at a distance of 0.6 mm from the sensor surface. Thermocouples were connected to a datalogger. Measured data were recorded at a frequency of 1 000 Hz for each sensor. A heater was used to heat the experimental plate to an initial temperature of 320°C. A cooling zone was mounted on the laboratory equipment in the required position. A pneumatically driven deflector was positioned between the surface and the cooling zone. It was used to reflect the water from the roll surface while setting the experimental parameters. When the plate was heated, rotation velocity and water pressure/flow rate were set, the deflector was open and water sprayed on the rotating roll surface. The experiment was finished after the plate reached ambient temperature. The heat transfer coefficient, heat flux and the surface temperature were computed using the inverse method [9].

3. RESULTS AND DISCUSSION

3.1. Impact of various emulsions on a cooling intensity

An experimental study of an emulsion's composition was tested. The static experimental stand (Figure 1) was used. The goal of the first experimental setup was to compare the cooling efficiency of emulsions based on different oils and concentrations. Palm, Coconut and Lard oil-based emulsions were prepared. The heat transfer coefficient was comparable for all three emulsions (**Figure** on the left graph). The concentration of the oil in the emulsion has a significant influence on the heat transfer coefficient which decreases with increasing oil concentration. The result for the lard oil-based emulsion is shown in **Figure** on the right.

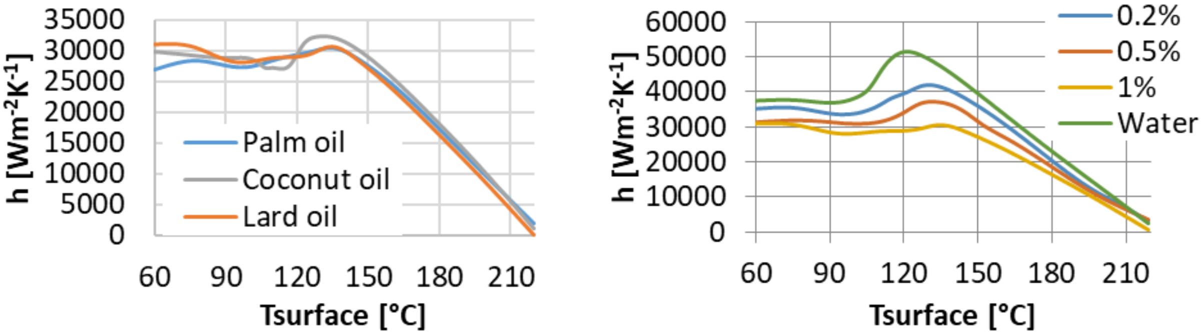

Figure 2 Heat transfer coefficient dependence on the surface temperature for various emulsions (on the left graph) and lard oil concentrations (on the right graph).

3.2. Cooling optimization

Cooling process optimization was the next logical step when the influence of various emulsions was negligible. The experimental stand Roll was used for the activity (chapter 2). First, the actual cooling configuration with a single header was tested to have a reference heat transfer coefficient. Cooling configurations examples of of the bottom roll exit side cooling are shown in **Figure 2** (on the left side). Three different water pressures were studied – 5, 4.2 and 3.4 bar. It was found that the heat transfer coefficient was comparable (**Figure 3** on the left side). So, the decrease in water pressure to 3.4 bar caused water flow rate savings of 17% without any effect on cooling efficiency. A study of other experimental parameters (nozzle type, size and span, cooling header and inclination angle position, etc.) followed, and two examples of results are shown below. The water temperature did not influence the heat transfer coefficient **Figure 3** on the right side). Interesting results were obtained in the study of the nozzle offset angle setup (nozzle rotation around its axis). 0° means that the jet is spraying horizontally and 90° represents a vertically spraying jet. Interestingly, the change of the offset angle from 50° to 30° did not significantly influence the heat transfer coefficient (Figure 4 on the left side). Based on the experimental results, two new cooling configurations were tested – two header system with flat jet nozzles and a combination of flat jet and full cone nozzles. The visualization for the exit bottom roll side of these configurations is shown in Figure 2 (center and right picture). The heat transfer coefficient distribution on the roll surface is shown in **Figure 4** (on the right side). The advantage of the new system is a wider cooling area for both new cooling configurations. The combination of full cone and flat jet nozzles decreases water consumption by 25% with higher cooling efficiency. The top roll and entry sides were also studied.

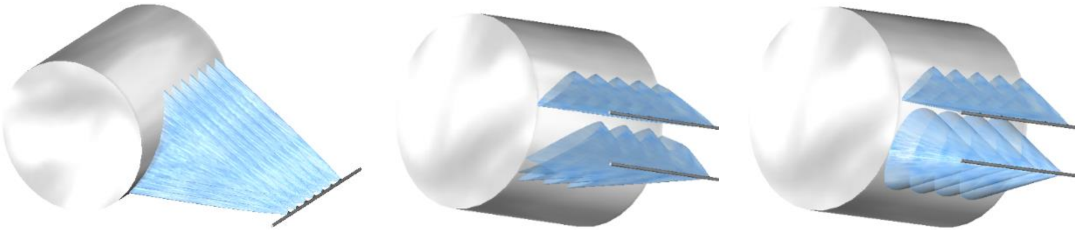

Figure 2 Examples of bottom roll cooling configurations – a single header on the left side, two headers with flat jet nozzles in the center and a combination of full cone and flat jet nozzles (on the right side).

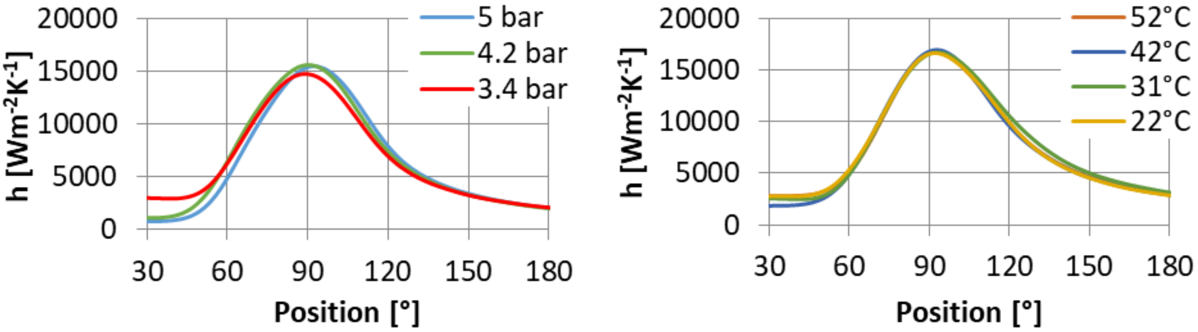

Figure 3 Examples of the heat transfer coefficient study – single header, various water pressures (on the left side) and water temperature (on the right side).

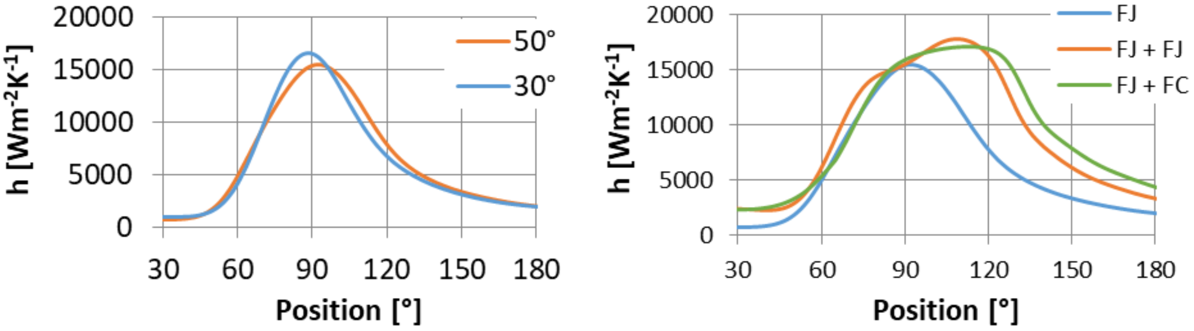

Figure 4 Example of the heat transfer coefficient for the single header and two different offset angles (on the left side) and various cooling configurations (on the right side, see Figure 2).

3.3. Cooling simulations

Three cooling simulations were run using the laboratory software Simroll. The Simroll used temperature dependent initial conditions (**Figure 5** on the left). Heat transfer coefficient dependence on the roll position was used as a boundary condition (an example is shown in **Figure 5** on the right). Cold rolling uses emulsions instead of water, so the h value was lowered by 30%. The heat transfer between the roll and the strip was defined by a heat transfer coefficient of 80 000Wm^{-2}K^{-1}. The strip temperature was set to 200°C in the simulation. This value was obtained from the industrial partner. The accuracy of the heat transfer coefficient and maximal strip temperature in the roll bite was verified by comparing the final roll temperatures on a pilot mill. The emulsion temperature was set to 60°C. The simulation results are shown in **Figure 6**. The advantage of a new cooling system (FJ + FC) was a decrease in the roll temperature by 5°C (**Figure 6** on the right). The slight difference is caused by the high coolant temperature. The final simulation was done for the single header cooling system and the water of 20°C as a coolant. The advantage of a decreased saturated roll temperature was significant. The difference was 35°C.

Temperature [°C]	Density [Kg m^{-3}]	Capacity [kJ kg^{-1} K^{-1}]	Conductivity [W m^{-1} K^{-1}]
20	7310	0.473	49.4
100	7290	0.473	47.3
200	7260	0.49	44.4
300	7230	0.511	41.9
400	7200	0.532	38.9

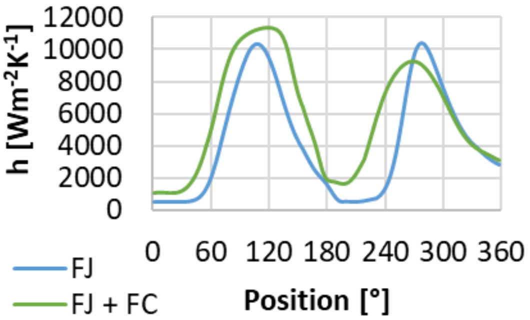

Figure 5 Roll material properties (on the left side) and example of boundary conditions used in simulations of bottom roll cooling.

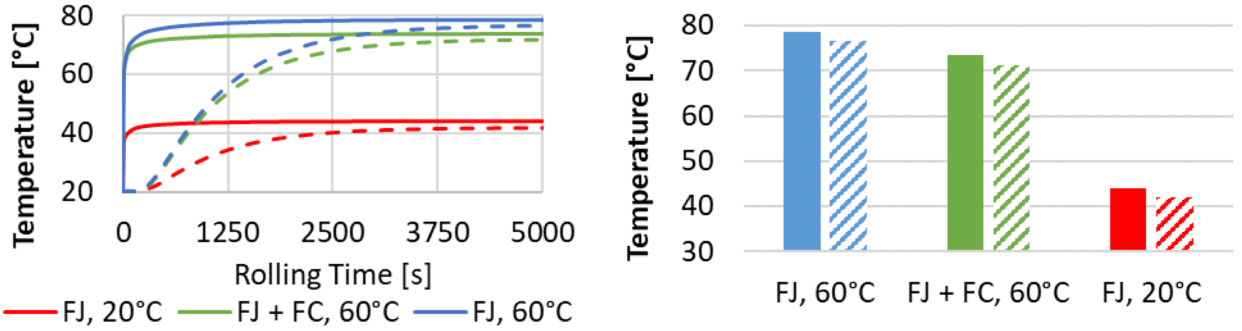

Figure 6 Simulation results for three cooling configurations - single cooling header FJ with emulsion of 60°C (blue)and water of 20°C as a coolant (red line) and the third configuration with two headers using flat jet and full cone nozzles (FJ+FC) and emulsion of 60°C as a coolant. Temperature evolution is shown on the left side and saturated roll temperature is shown on the right graph (standard line for the roll surface temperature and dashed lines for the center)

4. CONCLUSION

The final goal of the research was to study cooling performance possibilities to increase cold rolling mill capability by increasing strip thickness reduction per stand and rolling speed which increases heat generation in the roll bite. The first idea was to study the influence of various emulsions and oil concentrations on the cooling intensity. The presence of oil decreases the heat transfer coefficient (1% concentration -> 30% decrease). The difference in usage of palm, lard or coconut oil does not influence the cooling intensity. The second step was to optimize the cooling system. The target was to enhance cooling and safe water consumption. Extensive experimental research followed and the influence of several cooling parameters was studied (water pressure, nozzle size, nozzle type, nozzle position, water temperature, etc.) The final cooling configuration was composed of a flat jet and full cone nozzles fixed on two headers. The water consumption savings were 25 % and the heat transfer coefficient increased. Cooling simulations were done to compare the advantages of the new configuration on a real rolling campaign. The roll temperature decreased only by 5°C (from 79 to 74°C) because of the relatively high coolant temperature. The last simulation was done for cold water (20°C) as a cooling medium instead of the emulsion. The saturated roll temperature decreased by 35°C. Therefore, separation of the cooling and lubrication would increase the cold rolling mill capability. This could be done by installing water knives on the exit and entry roll side, which can effectively remove water from the surface.

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