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The comparison of measured surface temperature of roll in stretch reducing mill with a simulation of process

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Abstract. This paper deals with the surface temperature of rolls during hot rolling of seamless steel tubes in stretch reducing mill in Zeleziarne Podbrezova. The main goal of our work was to measure the temperature of the rolls and compare it with the results coming from numerical simulation of hot rolling process. In general, the temperature of the tubes after stretch reducing should be higher than A_{r3} by 30 ÷ 50 °C. The surface temperature of selected roll (so called "B-roll") was measured by means of a contact thermocouple-based method. Boundary conditions for numerical simulation of hot rolling process was set up according to the actual process conditions during rolling.

1 Introductions

The rolling process in a stretch reducing mill on Figure 1 (SRW) marks the final hot forming operation in seamless steel tube production process.

In this process, a hollow tubular feedstock passes a series of 3-roll rolling stands with oval or circular rolling gap. The hollow undergoes gradual reduction of outer diameter and wall thickness, achieving final tube dimensions and final mechanical properties after exiting the mill and cooling on a cooling bed [1 ÷ 5]. The process itself does not use any internal tool; the rolls in the stands do all the job. In general, stretch reducing mills can be used to extend the production range for small- and medium-diameter hot rolled tubes [1 ÷ 7]. The main purpose is searching of the ideal value of HTC between roll-nozzle and feedstock roll.

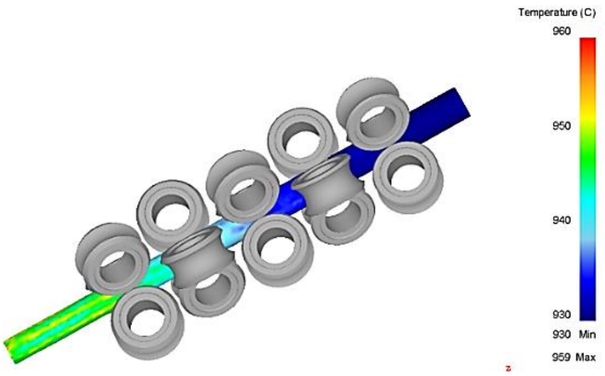

Figure 1 Numerical model of a stretch reducing mill

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2 Measurement methodology

When choosing the appropriate methodology of temperature measurement, two basic methods were at our hand: contact and contactless.

The contact method proved to be more suitable for measuring the surface temperature of the roll [8 ÷ 13]. Contactless measurement would be very difficult to use for several reasons (for instance the low emisivity of a rather glossy working surface of the roll, the presence of cooling water, steam etc.) Customized K-type thermocouple (TC) probe was used during our experiments. The standard deviation of thermocouple type K is ± 2.2 °C or 0.75 %. The measurement itself was carried out while the stretch reducing mill was put to a halt (cooling water and roll drives were turned off). The TC probe was put on the measurement spot of the working surface of the roll and the signal was recorded by a computer [11]. To ensure a reliable measurement, the following conditions need to be met [10–12]:

- Perpendicular orientation of the probe body with respect to the roll surface,
- The rectangular sensing ribbon should be aligned so that the longer side matches the roll circumference,
- The measurement spot should lie on the symmetry plane of the working surface of roll,
- The measurement should take at least 5 seconds while fulfilling all the conditions mentioned above.

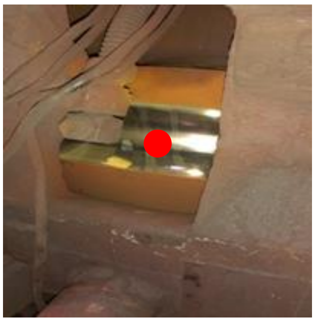

Figure 2. Detailed view on the working surface of the roll with red arrow pointing at the measurement spot when using contact temperature probe

2.1 Result of a measured temperature

The surface temperature of the roll was measured on the stand No. 3 and No. 5 under the specified conditions.

As can be seen in table 1 the surface temperature of the roll in stand No. 3 is on average temperature 99 °C after rolling campaign about 500 pieces of tubes. As can be seen in table 2 the surface temperature of the roll in stand No. 5 is on average temperature 97°C after rolling campaign about 500 pieces of tubes. The surface temperature of the roll after rolling the ideal number of pieces becomes stable and the temperature is in the range of ± 5 °C. On Figure 3 we see the illustrative measurement of surface temperature of rolls in the stretch reducing mill.

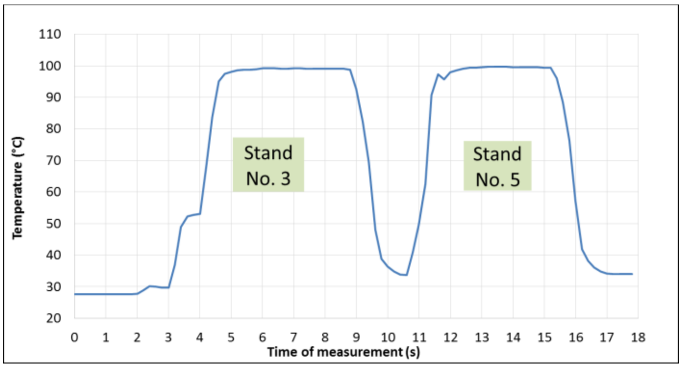

Figure 3. Illustrative record of surface temperature measurement in stands

Table 1. Values of measured temperature

Stand No.	T_{max} (°C)					
	Measurement No. 1	**Measurement No. 2**	**Measurement No. 3**	**Measurement No. 4**	**Measurement No. 5**	**Avg. temperature**
3	101	96	95	99	101	**99**
5	98	93	95	98	97	**97**

The rotating test bench is designed for investigation of cooling effects on the rotating cylindrical surfaces. The parameters of the bench are adapted to the main application which is design of cooling systems of rolling-mill working rolls [6–7]. The data obtained by the thermocouples during the roll cooling experiment gives information about temperature history at positions under the roll surface. Each data point is also connected to information about the angle of cylinder rotation and thus the data collected in "time" order can be converted into position order. The measured temperatures are used for calculation of heat transfer coefficient and surface temperature history [6–7].

3 Numerical simulation of SRW rolling process

3.1 Preparation of simulation
Simulation of SRW rolling process uses a 3D FEM model with given process and boundary conditions, considering significant heat transfer from the workpiece to the rolls and the environment (convection/HTC, radiation) and also spray water cooling of the roll surface (convection/HTC).

For given rolling simulation, process parameters for a given tube dimension were provided, such as the angular velocity of the rolls, initial temperature of the workpiece, etc. Various heat transfer coefficients (HTC) were used to monitor the heat transfer effects that were directly measured as the roll surface temperature using our sturdy TC contact probe.

3.2 Simulation run
A virtual rolling campaign with the series of twenty 16.4m long hollows was used to determine the roll surface temperature.

In this campaign, only stand No. 3 and stand No. 5 were considered. The actual length of the workpiece as well as the time of contact with the roll was recalculated for both rolling stands (as no full set of SRW stands was considered in simulations). The resulting contact time was 11 seconds, followed by 6 second time gap.

3.3 The temperature of roll through continual transition of tubes in stretch reducing mill
For roll in stand No. 3 the feedstock temperature was set to 925 °C, which corresponds to the temperature reading obtained from IMS temperature measurement system that senses temperature of input feedstock prior to entering the SRW mill (the actual temperature was approx. 940 °C; we considered some temperature drop due to 1st and 2nd rolling stand).

The temperature measurement point was selected at the center of the square of the working surface of the roll. On Figure 4 and Figure 5 we see the result from simulation for roll temperature in the stand No. 3.

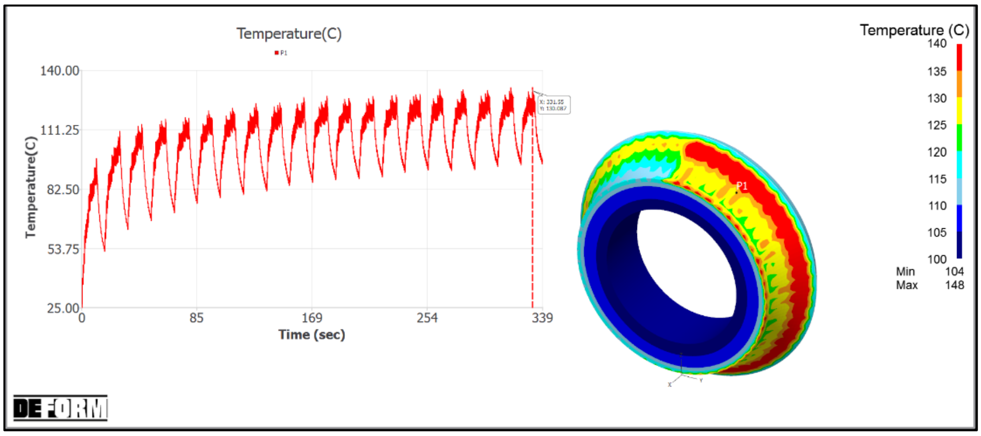

Figure 4. HTC roll-feedstock was measured to 13200 W/m^{2}K, maximal HTC roll-nozzle to be HTC 8100 W/m^{2}K at 100 °C

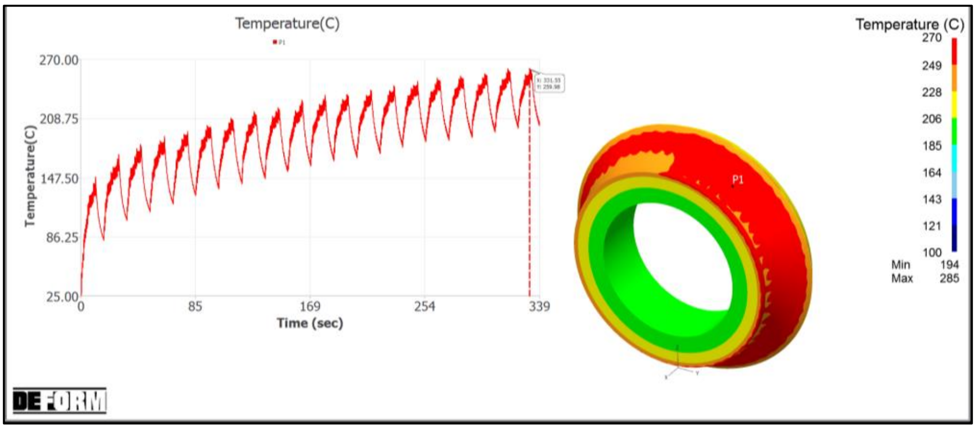

Figure 5. HTC roll-feedstock was raised to 22000 W/m^{2}K, maximal HTC roll-nozzle was measured to be 2400 W/m^{2}K considering that temperature 100 °C

For roll in stand No. 5 the feedstock temperature was set to 881 °C, which corresponds to the temperature reading prior to stand No. 5 using the pyrometer. On Figure 6 and Figure 7 we see the result from simulation for roll in the stand No. 5.

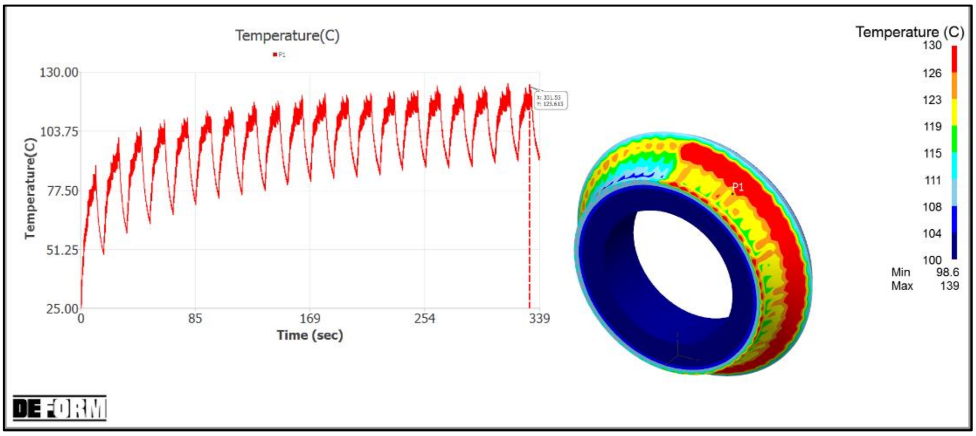

Figure 6. HTC roll-feedstock was measured to 12100 W/m^{2}K, maximal HTC between the roll and the nozzle to be HTC 8100 W/m^{2}K at 100 °C

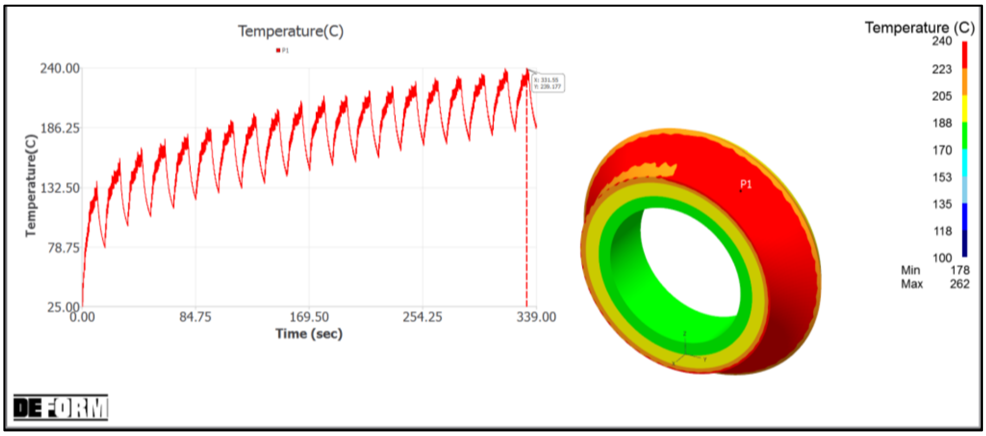

Figure 7. HTC roll-feedstock was raised to 20600 W/m^{2}K, maximal HTC roll-nozzle was measured to be 2400 W/m^{2}K at 100 °C

4 Results and Discussion

4.1 Result of a simulation
In the table 2 we see the resulting roll temperature (stand no.3 and stand no. 5) at the same point of continuous passage and permanent load.

We can say that the effect of HTC has a significant effect on the resulting temperature (average temperature from last peak, which see in table 2). With the same HTC roll-nozzle but with a different HTC roll-feedstock the difference in the resulting temperature on the stand No. 3 to 50 °C. Although, when changing the roll cooling intensity, the same HTC feedstock-roll (22000 W/m^{2}K) also has difference of up to 40 °C. As we can see from graphs above, the temperature itself is gradually settling (Figure 4, Figure 5, Figure 6 and Figure 7). This is due to the equilibrium state between the temperature received from the feedstock and the ambient temperature and reduced by the influence of the cooling of the roll by the medium.

Table 2. Average surface temperature on the roll

Surface temperature (°C)		HTC feedstock ($T_{feedstock}$ – 925 °C) – roll in stand No. 3	
		13200 W/m^{2}K	**22000 W/m^{2}K**
HTC roll–nozzle	**2400 W/m^{2}K**	133 °C	181 °C
	8100 W/m^{2}K	112 °C	141 °C
Surface temperature (°C)		**HTC feedstock ($T_{feedstock}$ – 881 °C) – roll in stand No. 5**	
		12100 W/m^{2}K	**20600 W/m^{2}K**
HTC roll–nozzle	**2400 W/m^{2}K**	123 °C	167 °C
	8100 W/m^{2}K	106 °C	132 °C

4.2 Discussion
When comparing the temperatures between simulation and the operating measurements, we can define boundary conditions to simulate the reduction process for a larger campaign.

The most suitable results were simulations using the HTC roll-nozzle 8100 W/m^{2}K and HTC feedstock-roll by HTC 13 200 W/m^{2}K. It is important to extend the rolling campaign to a similar number of pieces as it was actually rolled out using the same method. When comparing surface temperatures in simulations and experimental measurements, it is necessary to point to similar temperatures under the aforementioned boundary conditions. The temperature variation of the simulations to the measurements was caused by the transition of the feedstock over the remaining number of stands and reducing it. This effect caused a difference of 12 °C on average compared to the real measured values that were measured after the feedstock stretch reducing process. It is necessary to adjust the steady state from experimental measurement of HTC with real values of surface temperature of the rolls.

5 Conclusion

The results achieved were supported by results of modelling and simulation of heat transfer between the rolls and the tube [3].

The experiment confirmed the assumption that it is possible to obtain very similar values of the surface temperature of the roll as in the real measurement as well as in the simulation of the experimental rolling campaign. From this we propose to continue the experimental modeling of this process to a negligible difference of ± 5 °C.

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