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NUMERICAL MODELLING OF THE COOLING ABILITY OF DEVICE FOR THE PLAIN ROUND BARS ACCELERATED COOLING PROCESS

NUMERYCZNE MODELOWANIE ZDOLNOŚCI CHŁODZĄCEJ URZĄDZENIA DO PRZYSPIESZONEGO CHŁODZENIA PRĘTÓW OKRĄGŁYCH GŁADKICH

The paper presents numerical modelling results of the band accelerated cooling during rolling process. For the numerical modelling the Forge3® and the SortRoll computer programs were used, which based on finite element method.

Research were carried out for one of the bar rolling mill technological conditions. The studies were carried out for 30mm-diameter plain round bars. Constructional steel S355J2G3 (according to DIN St 52-3) was used for the research.

The paper purpose was determination of the cooling ability of device for accelerated cooling process to checking possibility of the using this device in the rolling line, during normalizing rolling process. Investigation results elaborated in the paper made the basis for determination of the heat convection coefficients between cooled band and water for different pressure and water flow.

Keywords: numerical modelling, accelerated cooling, bars normalizing rolling process, S355J2G3 constructional steel

W pracy przedstawiono wyniki numerycznego modelowania procesu przyspieszonego chłodzenia pasma podczas walcowania. Do modelowania matematycznego wykorzystano komputerowe programy FORGE3® oraz SortRoll oparte na metodzie elementów skończonych.

Badania przeprowadzono dla warunków technologicznych jednej z walcowni prętów. Przedstawione w pracy badania przeprowadzono dla prętów okrągłych gładkich o średnicy 30mm. Materiałem wykorzystanym do badań była stal konstrukcyjna S355J2G3.

Celem pracy było określenie warunków chłodzenia w urządzeniu do przyspieszonego chłodzenia pasma pod kątem sprawdzenia możliwości zastosowania tego urządzenia do chłodzenia prętów w ciągu walcowniczym, podczas walcowania normalizującego. Opracowane wyniki badań stanowiły podstawę do wyznaczenia współczynników przejmowania ciepła przy chłodzeniu pasma wodą dla zmiennego ciśnienia i różnych przepływów wody.

1. Introduction

There are composite heat exchange conditions inside devices for the band accelerated cooling process during or after the rolling process. It is convection to the transfluent water, radiation to the surrounding steam atmosphere and convection to the water and steam mixture. There are a little published methods of the total heat exchange coefficient calculation in this conditions [1]. Differences of the heat exchange coefficient values inside cooling devices come from using by individual authors different research methods for calculation of this coefficient, among other things [2]. Moreover there are a little data and formulas in the technical literature for accurately calculation of heat exchange coefficients during band cooling process by using high-pressure water systems [3].

2. Purpose and scope of the study

The paper purpose was determination of the cooling ability of device for accelerated cooling process to checking possibility of using this device in the rolling line, during normalizing rolling process. Investigation results elaborated in the paper made the basis for determination of the heat exchange coefficients between cooled band and water for different pressure and water flow value.

Research were carried out for one of the bar rolling mill technological conditions. The studies were carried

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out for 30mm-diameter plain round bars. Constructional steel S355J2G3 (according to DIN St 52-3) [4] was used for the research.

As a results of carried out computer simulations the temperature distribution in the material for analyzed variants were obtain.

In the next stage of this paper numerical modeling of the normalizing rolling process with accelerated cooling of band in the final stage of the rolling process were carried out. In this investigation heat exchange coefficients between band and cooling medium (water), which were determinated with allowance of cooling possibilities of investigated device for band accelerated cooling were used.

3. Analysis of the investigation results

Currently, the process of rolling 30 mm-diameter round bars is carried out in 14 successive passes. After the band had been rolled in 14 rolling stands, it was air cooled up to the point of entering the accelerated cooling device.

The rolling process parameters used in numerical modelling of rolling 30 mm-diameter plain round bars are given in Table 1. The data in this table were calculated based on relationships described in reference [5]. The temperature of the rolls was assumed based on industrial test results [6].

Table 2 shows data concerning water flow and pressure for respective cooling variants, as obtained from the Rolling Mill Department. This table provides also the values of the heat convection coefficient between the material being cooled and the water, as selected based on the obtained industrial test results using the inverse method, which are described in detail in work [7].

Figures 1÷2 represent band temperature distributions, as computed numerically using the FORGE3® software [8] immediately before and after the cooling device, respectively, for the variants under analysis.

TABLE 1

Input data for the computer simulations of the 30 mm-diameter plain round bars rolling process

Air temperature, [°C]	Rolls temperature, [°C]	Friction factor, [–]	Friction coefficient, [–]	Coefficient of heat transfer between band and air, [W/m^{2}K]	Coefficient of heat transfer between band and rolls, [W/m^{2}K]
20	60	0,8	0,3	100	3000

TABLE 2

Main parameters of the cooling process used during research

	Band linear speed [m/s]	Accelerated cooling time of band [s]	Water flow [m^3/h]	Water pressure [bar]	Heat convection coefficient between material and cooling medium (water) [W/m^{2}K]
Variant 1	3,19	0,43	110	12	18000
Variant 2	3,19	0,43	75	6	9000
Variant 3	6,50	0,21	75	6	18000
Variant 4	6.50	0,21	110	12	9000

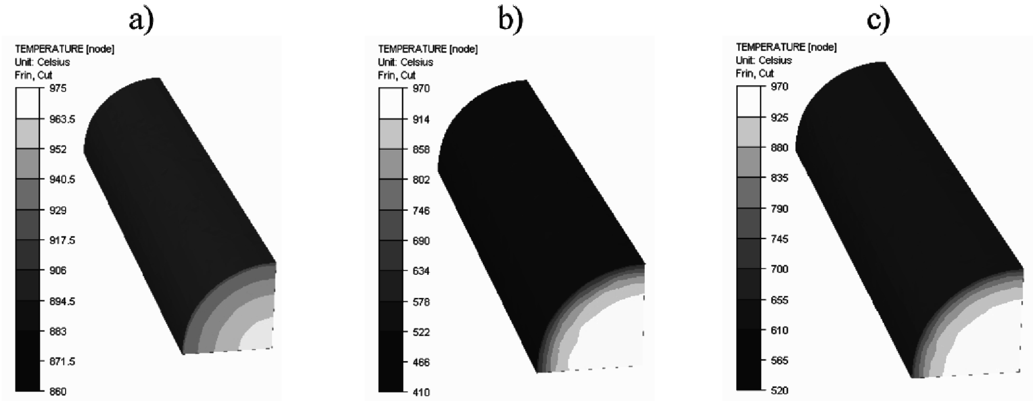

Fig. 1. Band temperature distribution [°C] computed for the variants 1 and 2: a) before cooling device (variant 1 and 2), b) after cooling device (variant 1), c) after cooling device (variant 2)

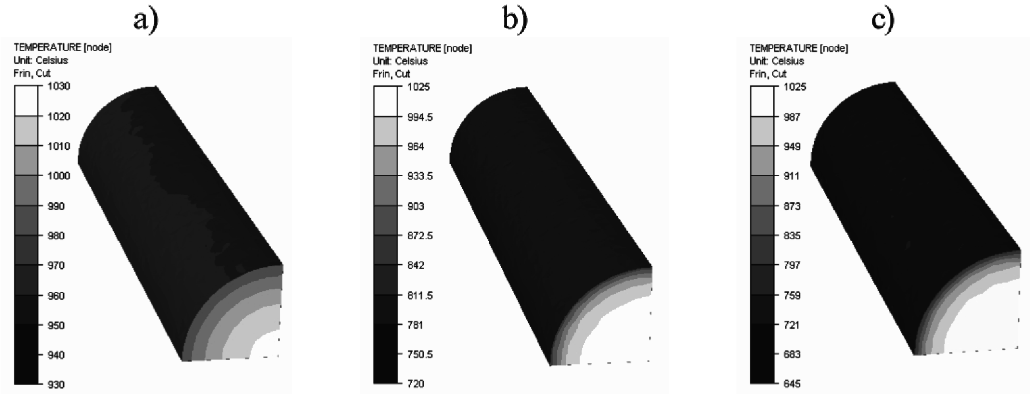

Fig. 2. Band temperature distribution [°C] computed for the variants 3 and 4: a) before cooling device (variant 3 and 4), b) after cooling device (variant 3), c) after cooling device (variant 4)

By analyzing the data in Figure 1a it was found that the average band temperature immediately before the cooling device for Variant 1, as computed numerically, was 950°C, while the band surface temperature was approx. 927°C. The band temperature difference on the cross-section was in this case about 23°C.

After analysis of the data in Figure 1b it was found that the average band temperature immediately after the cooling device for Variant 1, as computed numerically, was in this case about 795°C, while the band surface temperature was approx. 615°C. The band temperature difference on the cross-section was about 355°C.

Upon the analysis of the test results for Variant 2 (Fig. 1c) it was found that the average temperature of the band immediately after the cooling device, as computed numerically, was approx. 850°C, while the band surface temperature was about 720°C. Whereas, the band temperature difference on the cross-section was about 250°C.

By comparing the temperature test results for Variants 1 and 2 it is found that better results were obtained using Variant 2. The temperature difference on the band cross-section, as obtained using Variant 2, is smaller compared to Variant 1, which will result in faster equalization of the band cross-section temperature at the subsequent stages of the rolling process. However, reducing the rolling speed from 6.5 m/s, as presently used, down to a speed of 3.19 m/s would lower the output of the Rolling Mill.

By analysing the test results for Variant 3 (Fig. 2a) it was found that the average temperature of the band immediately before the cooling device, as computed numerically, was approx. 1002°C, while the band surface temperature was about 980°C. The band temperature difference on the cross-section was in this case about 22°C.

From the analysis of the data in Figure 2b it was found that the average temperature of the band immediately after the cooling device for Variant 3, as computed numerically, was in this case about 940°C, while the band surface temperature was approx. 855°C. The band temperature difference on the cross-section was in this case about 170°C.

Upon the analysis of the test results for Variant 4 (Fig. 2c) it was found that the average temperature of the band immediately after the cooling device, as computed numerically, was approx. 904°C, while the band surface temperature was about 785°C. Whereas, the band temperature difference on the cross-section was about 238°C.

By comparing, in turn, the temperature test results obtained for Variants 3 and 4 it is found that better results were obtained using Variant 3. The temperature difference on the band cross-section, as obtained using Variant 3, is smaller compared to Variant 4, which will result in faster equalization of the band cross-section temperature at the subsequent stages of the rolling process.

When analyzing the test results represented in Figures 1b, 1c and 2b, 2c it can be observed that primarily the thin surface layers of the band undergo rapid cooling as a result of accelerated cooling applied.

By comparing the temperature distribution results obtained from numerical modelling with the temperature values measured under industrial conditions using a thermovision camera, which are described in detail in work [7], it is found that the band temperature values obtained from numerical modelling correspond with high accuracy to the values measured in industrial conditions. The error between the band surface temperature values computed numerically and measured in industrial conditions ranged from 1.5% to 3.7%.

The temperature distribution results for all analyzed variants before and after the cooling device are summarized in Table 3.

This table provides also the temperature values measured in industrial conditions along with the error between the temperature values computed numerically and measured.

By comparing all the test results it is found that the best cooling variant is Variant 3. The temperature difference on the band cross-section, as obtained using Variant 3, is the lowest of all the variants examined, and what is more, this variant does not require the rolling speed to be reduced, owing to which the Rolling Mill's output will not decrease.

Within the next part of the work numerical modelling of the process of normalizing rolling of 26 mm-diameter round bars was carried out, while using accelerated cooling according to Variant 3.

To assure the average band temperature after the normalizing rolling process for the steel under examination to be obtained at a level of 900°C [9], two sections of accelerated cooling were employed. Modifications to the technology of rolling 26 mm-diameter round plain bars in 14 successive passes were proposed, which consisted in the transferring of rolling from rolling stands no. 13 and 14 to rolling stands no. 17 and 18. The implemented modifications included also the use of accelerated cooling after rolling stand no. 12. For numerical studies, the SortRoll program [10] was employed.

The values of heat transfer coefficients and other data required for performing computer simulation of the rolling process under analysis, either calculated or taken from literature [2, 11÷14], are given in Table 4.

TABLE 3

Temperature distribution results during accelerated cooling process of the 30 mm-diameter plain round bars

Wariant number		Computed band temperature, [°C]					Lateral surface temperature measured in the industrial conditions, [°C]	Error δ, [%]
		Average temperature	Lateral surface temperature	Temperature difference on the cross-section	Decrease of the average temperature	Decrease of the lateral surface temperature		
V1	Before	950	927	23	155	312	–	–
	After	795	615	355			602	2,2
V2	Before	950	927	23	100	207	–	–
	After	850	720	250			701	2,7
V3	Before	1002	980	22	62	125	–	–
	After	940	855	170			844	1,3
V4	Before	1002	980	22	98	195	–	–
	After	904	785	238			757	3,7

TABLE 4

Input data for the computer simulations of the 26 mm-diameter plain round bars rolling process

Ambient temperature [°C]	Rolls temperature [°C]	Water temperature [°C]	Friction factor [–]	Heat transfer coefficient between band and air [W/m^2·K]	Heat transfer coefficient between band and rolls [W/m^2·K]	Heat convection coefficient between band and water [W/m^2·K]
20	60	25	0,8	107 ÷138	3000 ÷ 9815	9000 (in the first section of the cooling device)
						9000 (in the second section of the cooling device)

The main rolling process parameters, as obtained from the Rolling Mill Department, are given in Table 5. This table provides also average strip temperatures before and after each pass, as obtained from numerical modelling, which included accelerated cooling after rolling stand no. 12. The initial temperature value was assumed based on measurements taken during the actual rolling process using a thermovision camera.

The temperature distribution and the average band temperatures obtained from the performed computer simulations which allowed for accelerated cooling after rolling stand no. 12 are shown in Figs. 3÷8. These figures represent results for band temperature distribution on the cross-section and over the length of the band.

TABLE 5

Main parameters of the 26 mm-diameter plain round bars normalizing rolling process

Stand no.	Groove type	Band output speed, [m/s]	Band average temperature, [°C]	
			before pass	after pass
1H	Box	0,21	1120	1110
2V	Box	0,27	1103	1094
3 H	Box-oval	0,37	1088	1081
4V	Round	0,49	1075	1070
5 H	Oval	0,72	1064	1059
6V	Round	0,98	1054	1052
7 H	Oval	1,35	1041	1040
8V	Round	1,86	1037	1038
9 H	Oval	2,48	1037	1038
10V	Round	3,33	1036	1040
11 H	Oval	4,39	1037	1038
12V	Round	4,96	1035	1037
13 H	Accelerated cooling			
14V				
15 H	–			
16V	–			
17 H	Oval	6,34	898	898
18V	Round	7,56	896	896
H – horizontal rolling stand, V – vertical rolling stand				

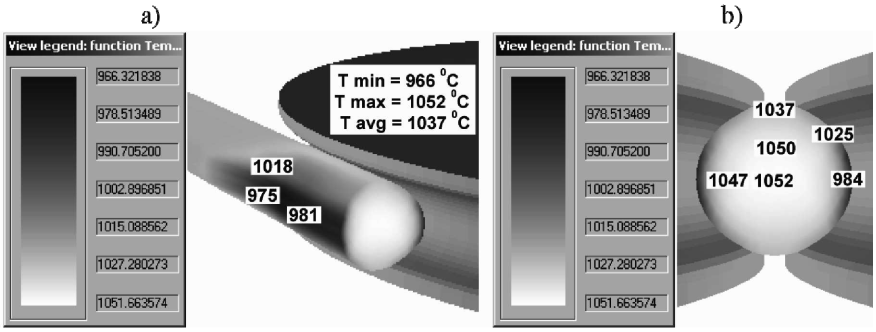

Fig. 3. Band temperature distribution [°C] after rolling stand no. 12: a) – over the length of the band, b) – on the band cross-section

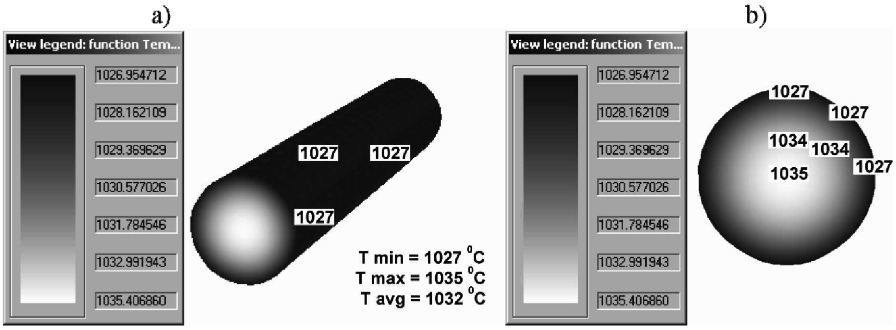

Fig. 4. Band temperature distribution [°C] before the first section of the cooling device installed in the rolling stand no. 13 place: a) – over the length of the band, b) – on the band cross-section

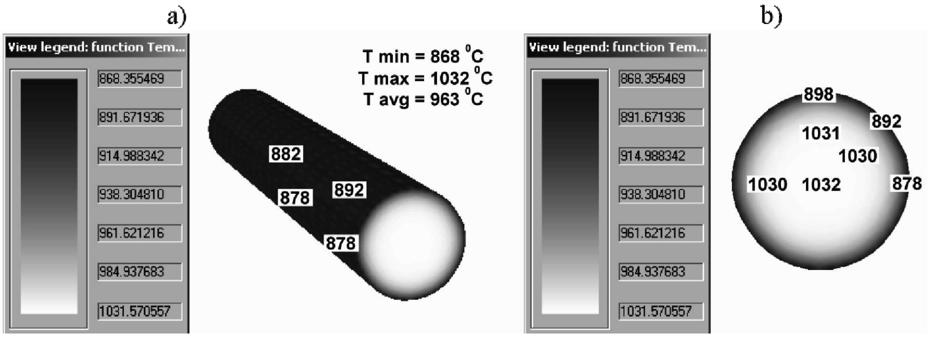

Fig. 5. Band temperature distribution [°C] after the first section of the cooling device installed in the rolling stand no. 13 place: a) – over the length of the band, b) – on the band cross-section

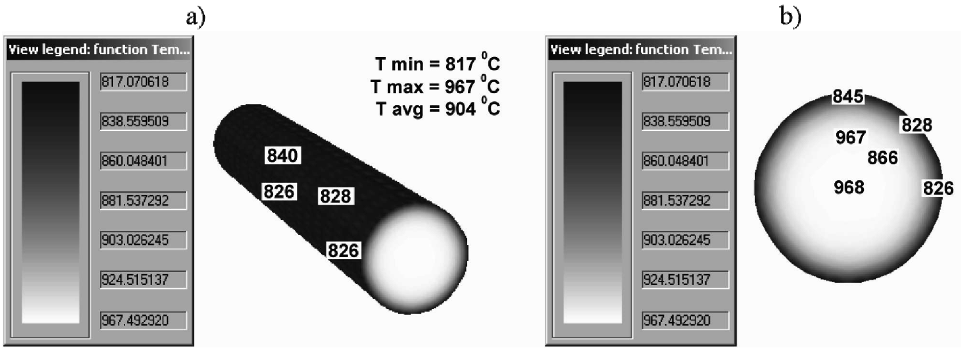

Fig. 6. Band temperature distribution [°C] after the second section of the cooling device installed in the rolling stand no. 14 place: a) – over the length of the band, b) – on the band cross-section

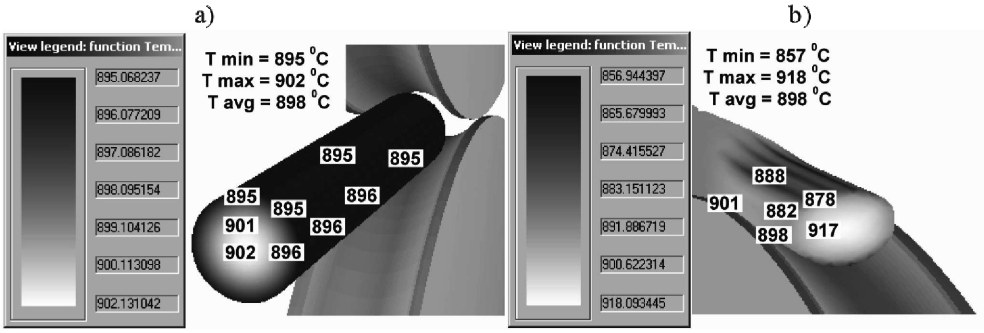

Fig. 7. Band temperature distribution [°C] in the rolling stand no. 17: a) – before pass, b) – after pass

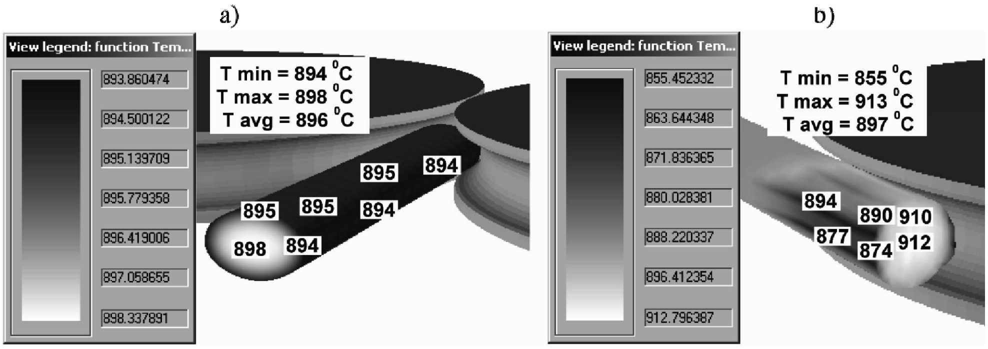

Fig. 8. Band temperature distribution [°C] in the rolling stand no.18: a) – before pass, b) – after pass

From the obtained results it has been found that the average temperature of the strip after rolling according to the new rolling scheme was approx. 900°C. So, it can be stated that the proposed method of cooling enables the required strip temperature level after rolling to be obtained.

4. Conclusions

From the conducted studies on the cooling capability of the plain round bar accelerated cooling device and upon the analysis of the obtained results, the following conclusions have been drawn:

- the band temperature distribution results obtained from numerical modelling for respective cooling variants correspond with high accuracy to the temperature values measured in industrial conditions;
- the initial and boundary conditions taken for numerical modelling were determined correctly;
- from the obtained test results it has been established that the best conditions for the accelerated cooling of band are provided by using Variant 3 of cooling;
- in the Bar Rolling Mill under study, it is possible to reduce the average band temperature down to a value of approx. 900°C, which is required for normalizing rolling;

- obtaining an average band temperature of about 900°C requires two accelerated cooling sections to be employed before the last two rolling stands;
- increasing the distance between the end passes will reduce the temperature difference on the rolled band cross-section, which forms as a result of applying accelerated cooling;
- installing a cooling device with the parameters and sizes examined is technically possible in the conditions of the Rolling Mill under study;
- the reduction of the rolling end temperature will have a favourable effect on the properties and structure of the finished product.

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