OPTIMISATION OF CHAMBER FURNACE TECHNOLOGICAL PARAMETERS FOR HIGH CHROMIUM STEEL ROLLS HEAT TREATMENT

Blaž Karpe, Simon Rečnik, Aleš Nagode, Borut Kosec
University of Ljubljana, Faculty of Natural Sciences and Engineering
Ljubljana
Slovenia

Sergej Novak
Valji d.o.o.
Štore
Slovenia

Stjepan Kožuh
University of Zagreb, Faculty of Metallurgy
Sisak
Croatia

Keywords: high chromium steel (HCS) rolls, heat treatment, chamber furnace, temperature optimisation

ABSTRACT
In this work, industrial control technical measurements of the heat treatment of high chromium steel (HCS) rolls is presented.
Measurements were carried out on the gas fired car bottom chamber furnace Bosio PP-KP 70/1150 in the company Valji d.o.o., Štore, Slovenia. Temperature measurements of the individual heating zones of the furnace, rolls surfaces, the external walls of the furnace and gas consumption were monitored throughout the whole process of heat treatment. The temperature profile of the rolls cross-section was calculated using computer simulation.
Periodical measurements of CO and NO_x *emissions were also carried out with the aim of combustion evaluation and ecological integrity.*
The successfulness of heat treatment was examined through microstructure observation, hardness measurement and the amount of retained austenite in the heat treated rolls.

1. INTRODUCTION
Company Valji d.o.o. is a manufacturer of industrial rolls for hot and cold rolling of sheet metal and processing of plastics and rubber. In the company strive for the development of new materials and technologies, achieving top quality, and high production. In the paper, control technical measurements of the gas fired car bottom chamber furnace (type PP-KP 70/1150 Bosio

d.o.o.) is presented. The furnace was introduced into production in 2008 and used for heat treatment of various types of rolls. Due to the demanding heat treatment, the control measurements of the furnace were performed on a batch of high chromium steel (HCS) rolls. With additional thermocouples, temperature of distinctive areas of the roll surfaces, temperature of individual heating zones in the furnace and temperature of the outer walls was monitored. Temperature distribution in the roller cross-section was calculated by computer simulation (FDM). From the point of view of cost estimation of the heat treatment, the consumption of gas was monitored throughout the entire heat treatment process. As each energy-intensive production is inextricably linked to the release of harmful emissions into the atmosphere, periodic measurements of CO and NO_x gas emissions were also carried out.
Rolls used for hot sheet metal rolling on continuous rolling mills are divided according to their position (stand) in the rolling mill (Figure 1). For initial roughing stand, high chromium iron rolls (HCI), high chromium steel rolls (HCS) or high speed steel rolls (HSS) are used. For initial finishing stands, HSS rolls, and to a lesser extent, the HCI rolls are most commonly used, while for the final finishing stands the rolls with the working shell made of high-alloyed nickel iron alloy with graphite (ICDP-Indefinite Chill Double Pour) or highly alloyed nickel-iron alloy with niobium and vanadium additions (CE-ICDP (carbide-enhanced ICDP rolls) are most commonly used. All types of the mentioned rolls are also manufactured in the company Valji d.o.o.

2. HIGH CHROMIUM STEEL (HCS) ROLLS

High chromium steel rolls are three layer type rolls (Figure 1) with the pearlite-ferrite nodular cast iron structure (NF 77) of the core, grey cast iron with lamellar graphite structure of intermediate layer and high chromium steel working shell with hardened martensitic structure, approximately 15 % of hard eutectic carbides M_7C_3 (M = Cr, Fe), and small amount of hard MC and M_6C primary carbides, due to vanadium and molybdenum additions. Chemical composition of the working shell is given in Table 1.

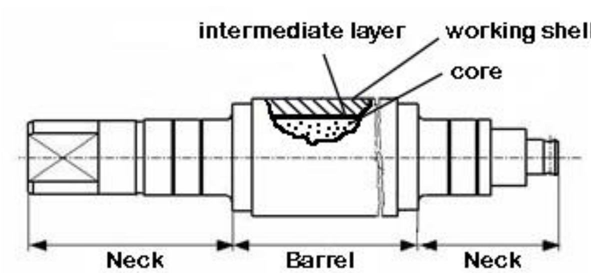

Figure 1. Roller cross section.

Table 1. Chemical composition of HCS rolls working shell

Wt.%	**C**	**Si**	**Mn**	**Cr**	**Ni**	**Mo**	**V**
min	1.0	0.5	0.6	10.0	1.0	1.0	0.2
max	2.0	1.0	1.2	13.0	2.0	2.0	0.5

The minimal thickness of the working shell of the HCS rolls is 70 mm. The HCS rolls have high compressive strength and toughness and are distinguished by their high wear resistance and high resistance to thermal fatigue. Excellent oxidation resistance at elevated temperatures and the formation of a stable oxide film on a working surface that does not peel and prevents the hot steel sheet from bonding to the roller surface, gives them the main advantage when used as rolls in the first roughing stands of continuous mill lines or single reversible roughing stands.

3. MANUFACTURING

High chromium rolls (HCS) are cast through a horizontal or vertical centrifugal casting process, in which the rotation of the mould (≈ 470 rpm) creates a sufficiently high centrifugal force to distribute the melt along the inner periphery of the hollow cylindrical die (Figure 2).

After the preparation of the melt, roll barrel working shell is poured, followed by the intermediate layer, which has the task to improve adherence between the core and working shell of the roll. When solidified two-layer working shell reaches the prescribed temperature, is transferred to the casting pit together with the die and placed vertically on the pre-prepared mould of the lower roller neck. The mould of the upper roller neck, feeding system, and pouring basin are installed. Temperatures of the working shell and the melt for the roller core play an essential role when casting the core of the roller. The temperature interval in which the roller working shell and the core are well joined is very narrow, only ± 10 °C. At temperatures too low, the working shell and the core will not agglutinate, and at temperatures too high, excessive re-melting of the intermediate layer or even working shell occurs.

Figure 2. Centrifugal casting of the working shell.

Heat treatment of high chromium steel rolls is a very time consuming process, lasting several weeks. Rolls are slowly heated up to 970 °C, into the two phase field (γ_{Fe} + M_7C_3). Since the rollers are thick-walled castings with a very large mass (> 35 tonnes), it is necessary to retain the heat several times in order to equalize the temperature throughout the roller cross-section (Figure 3).

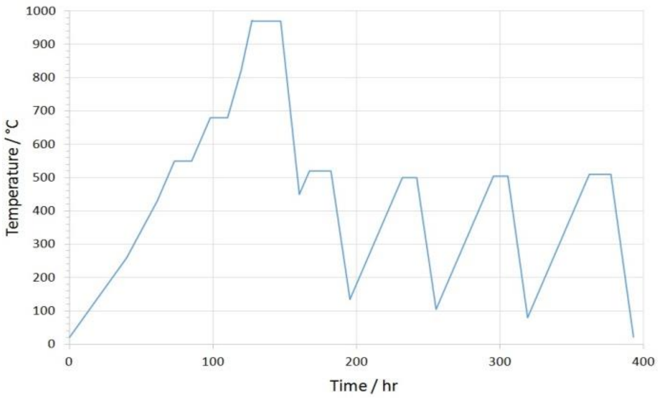

Figure 3. Heat treatment temperature profile.

The most critical temperature interval is below 500 °C, where the steel is not yet sufficiently plastic to compensate the thermal stresses due to unequal thermal expansion of the core and working shell and the release of residual casting stresses. Namely, both types of stresses have the same sign and are aggregated during the heating process, which can lead to cracks and consequently useless roller. Austenitization takes place at a temperature of 980 °C/ 20h. During annealing, the dendritic structure of austenite changes to a polygonal structure with surrounding network of eutectic carbides (Figure 4).

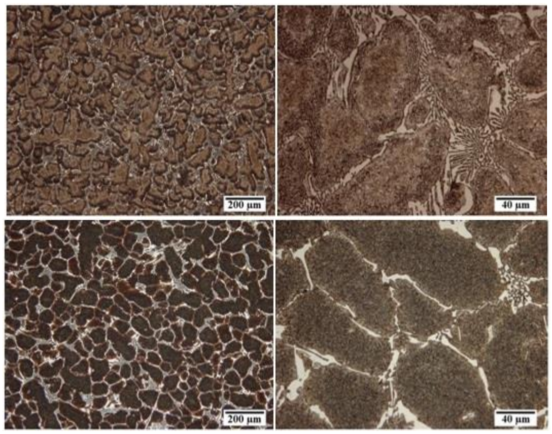

Figure 4. Microstructure of working shell of HCS rolls. Up: before heat treatment, bellow: after heat treatment.

These types of steels are characterized by the relatively high stability of austenite in a temperature interval between 350 °C and 525 °C. With rapid cooling from the austenitization temperature down to 450 °C and subsequent slow heating (10 °C/hr) up to 520 °C/12hr, the conditions for precipitation of secondary carbides from the austenite matrix are created. In the next phase of heat treatment, rolls are cooled to 135 °C, below the martensite start temperature ($M_s \approx 200$ ° C), and the part of the austenite is transformed into martensite. The amount of retained austenite is still high (> 40 %) at this stage and increases with the temperature from which the rolls are quenched and with the carbon concentration in the steel. By repeated heating up to a temperature of 500 °C, 505 °C and 510 °C, and intermediate cooling down to an ever-lower temperature as in the first cooling stage, austenite is progressively transformed into martensite, which in then tempered in the next heating step. Simultaneously, fine secondary carbides $M_{23}C_6$, which help to strengthen the matrix, precipitate from retained austenite. The final microstructure of the roll working shell consists of a tempered martensitic matrix with uniformly distributed secondary carbides $M_{23}C_6$, and small amount of MC and M_6C vanadium and molybdenum primary carbides surrounded by a network of eutectic carbides M_7C_3.

4. EXPERIMENTAL PART

Chamber furnace Bosio, type PP-KP 70/1150 serves in the company Valji d.o.o. for the heat treatment of cast rolls (Figure 5). Fuel for heating is Russian natural gas.

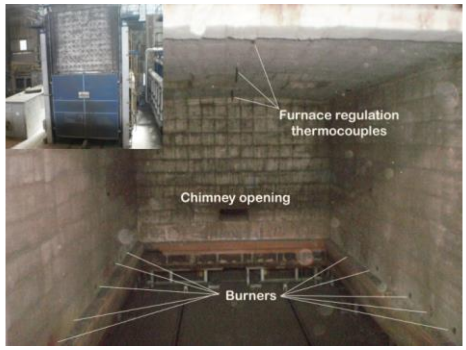

Figure 5. Furnace chamber.

The temperature in the furnace is controlled by the three thermocouples (PtRh-Pt; Type S) mounted on the furnace ceiling. Burners (12 pcs with 270 kW, maximum gas power 330 Nm^3/hr) are installed in a horizontal line on both side walls of the furnace, and divided in three temperature zones with individual regulation. The combustion air is preheated to a maximum temperature of 450 °C. Insulation of oven walls: 1. Insulfrax SF layer, thickness 13 mm, and 2. layer Fiberfrax Prismo-Block, quality Durablanket S 170/1200, thickness 300 mm.
The measurement of the surface temperature of the rolls was carried out on two equal HCS rolls, grade CCrS NF 77 (dimensions 1200 X 2000 mm, weight of individual roller 37.5 tons), with K-type thermocouples.
In order to prevent direct exposure to radiation, thermocouples were protected by high temperature resistant insulating wool ISOFRAX® and refractory brick. The roll necks are lined up due to the sagging at elevated temperatures under the influence of their own weight (Figure 6).

Figure 6. Protection against sagging.

Figure 7 shows the temperature profile on the surface of the rolls measured by the additional thermocouples. The temperature at the roller neck surface is slightly higher, which is understandable, since higher thermal conductivity of the roller core alloy (NF 77), smaller diameter, and the greater thickness of the gas layer above it. A slightly higher temperature on the lower part of the working shell is attributed to the convective influence, due to the direct flow of flue gases from the burners. The measured temperatures of the process in the furnace, the temperatures on the surface of the roller and the set temperature are well-matched, as no major temperature deviations have been detected.

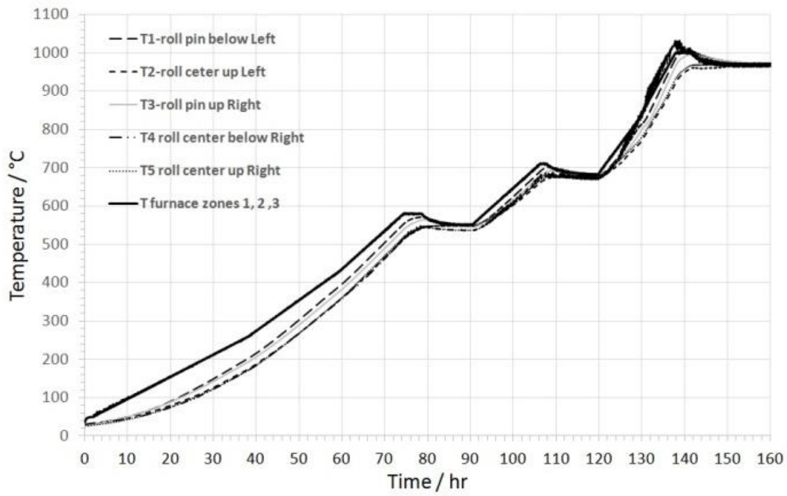

Figure 7. Temperatures of rolls surfaces and furnace heating zones.

The consumption of natural gas for the heat treatment of a batch (75 ton) of two HCS rolls was 18231 m^3. On the basis of the measured temperatures at various areas of the outer walls and the ceiling of the furnace, it was found, that the furnace does not have distinct thermal bridges, indicating an uncontrolled leakage of the furnace atmosphere or degradation of the insulation.

With the finite difference method (FDM) and computer simulation, it is established that the rolls are uniformly heated (Figure 8) throughout the cross-section with the prescribed temperature regime, and the temperature differences between the surface and the interior of the roll are not so significant to cause critical thermal stresses. Temperatures measured on the rolls surface were taken as boundary conditions for internal calculated temperatures of the roller cross-section.

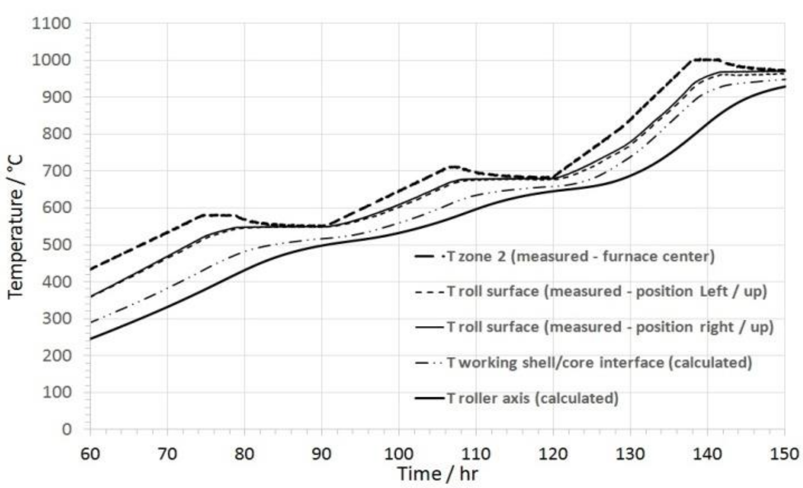

Figure 8. Temperature profile of the roller cross section.

Higher concentrations of CO at low temperatures in the furnace are the result of incomplete combustion due to local flame cooling, when still incompletely reacted hot flue gasses touch the cold pads and rolls. The auto-ignition temperature of CO is 609 °C and, as indicated in Table 1, the CO concentration is rapidly reduced at a temperature above 600 °C. On the other hand, the concentration of NO_x with increasing combustion temperature in the furnace increases, which is in accordance with the theory of NO_x formation.

Table 2. CO and NO_x concentration measurements

Meas. no.	$T_{furnace}$ [°C]	$T_{roll\ surface}$ [°C]	$T_{flue\ gases\ after\ recup.}$ [°C]	CO [mg/kWh]	NO_x [mg/kWh]
1.	70	36	40	/	/
2.	165	90	73	8115	0
3.	350	273	165,6	5183	12
4.	575	524	160,9	1540	17
5.	578	556	170,6	1186	19
6.	628	596	182,4	347	22
7.	683	679	186,9	55	44
8.	710	687	169,6	8	125
9.	824	787	209,9	0	205
10.	906	864	224,3	0	230
11.	993	983	230,7	0	241
12.	977	974	232,9	0	223
13.	288	232	125,5	6293	0
14.	504	498	155,2	2909	0

The main goal of the heat treatment of HCS rolls is the composition of retained austenite in the working shell structure during tempering. The amount of retained austenite is determined by the Feritscope® measuring device, which works on an inductive measurement of the magnetic permeability of the alloy. The measurement is relative to the standard and the proportion of the retained (non-magnetic) austenite acceptable low, if the measured value above 60.

Table 3. Hardness and Feritscope® measurements

Condition	Hardness (HRC)	Feritscope®
As cast	55.1	41.1
Quenched	57.7	72.5
Tempered	51.2	77.1

5. CONCLUSIONS

Standard material testing of HCS rolls and control measurements of the gas fired car bottom chamber furnace Bosio PP-KP 70/1150 were carried out. From the product quality point of view the heat treatment was successful. On the basis of the measured temperatures at different areas of the outer walls and the ceiling it was found that the furnace has no distinct thermal bridges, which would indicate an uncontrolled leakage of the furnace atmosphere or degradation of insulation and consequently unhomogenous temperature profile in the furnace. Only minor maintenance work has to be done on the selant between bottom car and furnace wall. By measuring the surface temperatures on the rolls and calculating the temperature profile over the entire cross section, we confirmed that the rolls were fully heated to the prescribed temperature. The increase in furnace productivity due to higher heating rate at lower temperatures could dangerously increase the risk of thermally induced roll cracking.

Regular control measurements of all production facilities contribute to quality assurance and reduce unnecessary costs due to production failure.

6. REFERENCES

[1] Internal documentation Valji d. o. o., Štore, 2017.,

[2] Drobne, M., Vuherer, T., Samardžić, I. Glodež, S.: *Fatigue crack growth and fracture mechanics analysis of a working roll surface layer material*, Metalurgija 53, 481-484, 2014.,

[3] Internal documentation Bosio d. o. o. Štore, 2018.,
[4] Belzunce, F. J., Ziadi, A., Rodriguez, C.: Structural integrity of hot strip mill rolling rolls, Engineering failure analysis 11, Elsevier, University of Oviedo, Campus Universitario, Gijon, Spain, 789-797, 2004.,
[5] Zihenberger, K. H., Windhager, M.: *Recent developments in HSM rougher rolls-risks and chances*, Eisenwerk Sulzau-Werfen, Tenneck, Austria., The Material Science and Technology Conference and Exhibition, Pittsburgh, Pennsylvania, USA, 38-41, 2005.