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Increasing of rolling mill rolls durability in operation – part II

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Abstract. By analyzing the situation in the industrial practice, was established that the structure obtained at the rolling mill rolls manufactured in the country according to classical technology does not ensure the necessary hardness and durability in operation.
The research carried out in operating conditions ensured the obtaining of structures that would give the rolls hardness as high as possible without diminishing the imposed toughness characteristics (resilience, elongation). From the variants experienced in operation, those with high technological and scientific value were selected, resulting that with the increase of resistance characteristics, the resilience did not decrease, and the exploitation durability doubled compared to the rollers processed by classical technology.

Keywords: structure, exploitation durability, toughness, resilience, primary thermal treatment, secondary thermal treatment.

1. Introduction

Rolling mill rolls are parts of the working stand ensemble subjected to complex stresses [1], which is why they must have high operating qualities determined mainly by hardness, strength and stability at high temperatures. These qualities also determine the resistance to sudden temperature variations during the rolling process [2].
In addition, the rolling mill rolls must give a high quality to the surface of the rolled materials and favor the catching of the metallic material. Therefore, the

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conditions that must be met by the material from which it is made depend on both the type of rolling mill and the nature of the metal material itself.
The lack of in-depth, theoretical and experimental research on thermo-mechanical processes that occur during rolling is an important factor that retains the possibilities of more rational exploitation of rolling mills in operation, making it difficult the possibilities of designing automatic systems for regulation and control of technological processes related to exploitation phenomena.
A current problem that causes unrest in metallurgical enterprises is the low durability in operation of rolling mills [3];[4].
The deforming metallic material primarily produces abrasive wear on the surface of the rollers. Repeating heating and cooling at each rotation of the rolls produces cyclic variations in temperature both in the surface layers of the roll barrel and in their section, being generators of variable stresses that together with mechanical stresses reach significant values that in many cases exceed the metallic material resistance limit [5]-[7].
Figure 1 shows the overview of the rolls in a quatro stand for hot strips. It is observed that the working rolls that come in contact with the metallic material and perform the deformation are of smaller diameter, compared to the external support rolls, of larger diameter. The latter aim to cancel the elastic deformations of the working rollers in order to ensure the constant thickness of the strip on the width at rolling.

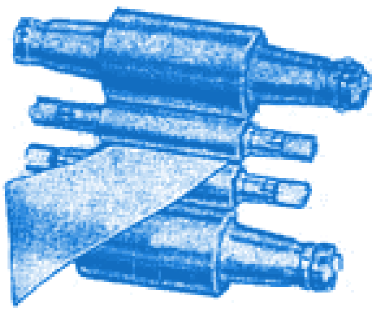


Fig. 1. Working rolling mill rolls (middle) and support (outer) for a quatro rolling stand.

The paper is a continuation of the research undertaken in Part I [8] and aims to improve the manufacturing technology and heat treatment of working rolls for hot strips of domestic steel type 85MoCrNi10, with increased durability in operation compared to imported rollers. This required the full use of the results known in practice, which only experience has allowed us to apply.
The work was performed on the basis of an economic contract with the Metallurgical Commercial Company from Hunedoara where the researches regarding the improvements brought to the technological processes of rolling mill rolls manufacturing were carried out, as well as at the Faculty of Engineering from Hunedoara where some aspects regarding the study of the thermal fatigue resistance of hot rolling mill rolls were finalized [9];[10].

2. Optimization of primary and secondary heat treatment

Primary heat treatment. The current quality requirements are best met by forged steel rolls, made of steel alloyed with chromium and nickel, or in some cases with other elements that form carbides (vanadium, molybdenum) [6].

After forging, the rollers of these qualities are subjected to the primary heat treatment, which consists of normalization, spheroidising annealing and dehydrogenation:

- Normalization, at 950°C with air cooling;
- Spheroidising annealing, at 820-600°C with furnace cooling;
- Dehydrogenation heat treatment, at 710°C with furnace cooling.

The aim of this treatment was the uniformization and finishing of the granulation, spheroidising the carbides in order to ensure a hardness that allows good machinability, dehydrogenation heat treatment bringing the material to a lower gas content, avoiding the appearance of flake defects and segregation cracks and ensuring a better ultrasonic transparency.

These qualitative characteristics are researched to be obtained by applying a single cycle of heat treatment.

For the execution of this type of treatment were used movable hearth furnaces that took over the rollers batch whose size was dictated by the condition that for each roller to ensure a minimum of 4 cubic meters hearth/furnace to assure a uniform heating by placement.

The primary heat treatment was performed in movable hearth furnaces, heated with methane gas, and the heating for normalization was performed at a speed of 50°C/hour so that when the furnace reaches the temperature corresponding to normalization, the entire load has the same temperature [11].

The maintenance time at the normalization temperature was calculated according to the diameter of the rolling mill rolls and the steel grade, so as to ensure the completion of the structural transformations (dissolution of carbides, homogenization of austenite).

The normalization of the rolls was carried out in air by unloading from the furnace and placing them on the supports to ensure the most uniform cooling. After cooling to 350°C, the rolls are reloaded in the furnace for pendulum spheroidising annealing at a heating rate of 50°C/hour to 820°C, maintained depending on the diameter of the rolls, followed by directed cooling at 15°C/hour to 600°C.

This stage of the primary heat treatment cycle is repeated twice and aims at spheroidising the lamellar perlite, as well as dissolving the carbide network which leads to an increase in the degree of hydrogen diffusion.

The next step of the primary heat treatment is dehydrogenation at 710°C with a holding time depending on the hydrogen content. The heating for this purpose was performed with 15°C/hour, followed by a directed cooling with 15°C/hour to a temperature of 400°C, the cooling process is continued together with the furnace switched off until it reaches 150°C, then air cooling.

After performing the primary heat treatment, the rolling mill rolls are received being subjected, for quality determination, to a preventive ultrasonic control, control of the appearance and dimensional, of the hardness of the rolls barrel and neck.
The mechanical characteristics resulting after the primary heat treatment, significant for the condition of the material with which the final treatment for the core of the rolls is entered, were determined on samples cut from the rolls barrel and neck.
The value level of these characteristics was in the field of:

- Hardness, HB………………….. ..208-285;
- Tensile strength, R_m ……………..700-950 N/mm^2;
- Yield strength, $Rp_{0,2}$……………...min. 550 N/mm^2;
- Elongation, A…………………….min. 10 %;
- Reduction in Area, Z …………….min. 20 %;
- Resilience, KCU…………………min. 20 J/cm^2.

From a macroscopic point of view, the steel for the rolls must not show visible defects with the naked eye, such as void, porosity, flakes, blowholes, cracks, non-metallic inclusions or strong segregation.
Microscopically, the annealed steel must have a pearlitic structure with uniformly distributed globular carbides. For this, the cyclic variation of the temperature was controlled with contact thermocouples, after which information the process was conducted.
Thus, for each load, 4 flexible thermocouples were used, placed at the corners of the load from the base and raised until the rolls barrel was reached, also at least one thermocouple was lowered from the arch until the load was reached.

Seconary heat treatment. This stage consisted of hardening in oil and high tempering [12]-[14], being applied to the rolls after the gauge reduction operation and aimed to obtain an improved structure throughout the rolls mass at the required hardness level, as well as the mechanical properties [15] required in operation.
The resulting temperature as optimal, for the secondary heat treatment was:

- Mass quenching 840-860°C, oil cooling;
- High tempering 500-570°C, oven cooling.

Vertical furnaces and basins were used for the quenching operation, and for the high tempering, the horizontal furnace from the heat treatment hall.
Also, at tempering, the way of placing the rollers was taken into account, so as to ensure a heating as uniform as possible, the rolls were spaced on metal supports with a height h=600mm.
It has also been established that because in the case of rollers, the high tempering consists of three pendulums, and the heating and cooling rate on tempering must not exceed 50°C/hour. After the last oscillation, the cooling was performed directed, at 20°C/hour to 150°C, then in air.
The qualitative characteristics obtained as a result of the temper hardening heat treatment were at the level of:

- Hardness, HB………………….. ..283-360;
- Tensile strength, R_m ……………..970-1230 N/mm^2;
- Yield strength, $Rp_{0,2}$……………...800-1000 N/mm^2;
- Elongation, A…………………….min. 10 %;
- Reduction in Area, Z …………….min. 30 %;
- Resilience, KCU…………………min. 30 J/cm^2.

Regarding the purity of steel, oxides, silicates, sulfurs and nitrides, each did not exceed the maximum value of 2.5.
Also, macroscopically the rollers must not show visible defects with the naked eye, and microscopically, the temper hardened rolls must have a uniform and fine structure, consisting of bainite, perlite and carbides, reaching in the center of the rolls at perlite and carbides.
After the treatment stage, the rollers are received by checking the appearance and quality characteristics.

3. Experiments with forged steel working rollers, steel grade 85MoCrNi10

The rollers manufactured in Hunedoara in order to eliminate the import are destined for the rolling of the strips and have the following dimensional characteristics:

- ϕ725 x 1250 x 3090 mm
- ϕ725 x 1100 x 2940 mm
- ϕ725 x 1000 x 2600 mm

It is observed that all rollers have the same diameter, only the length of the working barrel and the total length differ.
The chemical composition of the steel used is found in tables 1.

Table 1.

Chemical composition, %								
C	Mn	Si	Cr	Ni	Mo	Cu	P	S
0.80-0.88	0.60-0.80	0.20-0.40	1.80-2.10	0.90-1.10	0.20-0.30	max. 0.03	max. 0.03	max. 0.03

The characteristic elements of the manufacturing technology, consist in:
- Forging temperature 1200 ÷ 850 ° C;
- Soaking annealing temperature 660 ÷ 700 ° C;
- Hardness after softening annealing: max. 240HB;
- Quenching temperature 850 ÷ 880 ° C;
- Quenching cooling media: oil, air, air cooling tower;
- Hardness after quenching: 380 - 240HB;
- Tempering temperature 610 ÷ 620 ° C;

The required quality characteristics are represented by hardness and tensile strength [16]. The manufacturing cycle of the rolling mill rolls is long, starting with the elaboration of the steel and ending with the secondary heat treatment.
The elaboration was made in the electric arc furnace of 50 t. After the debate, the ingots are transported in a hot state for forging to the 1500KN press.

The realization of the rolling mill rolls of ϕ785 mm requires the repression of the ingots, operation being carried out as much as possible at temperatures close to the maximum temperature of the processing range.

At the beginning of the hot plastic deformation of the ingots, the closing and possibly the welding of the material defects take place, such as: microcracks, intercrystalline cracks, blowholes, fact that leads to the increase of the material compactness. In parallel with this, during the forging takes place the process of destruction of the casting structure, by recrystallization and diffusion.

After completion of forging, the grains do not remain elongated because the end of forging temperature is higher than the recrystallization temperature. So in order to obtain a structure as fine as possible and implicitly to obtain high mechanical characteristics, the forging end temperature must be taken into account.

After the forging operation, the rollers are placed in furnaces for primary heat treatment at temperatures of 550°C. This treatment aims at uniformizing and finishing the granulation and thus correcting the structure resulting from the hot plastic processing. It also ensures:

- obtaining a hardness that favors an easy machinability in order to repressing;
- elimination of steel gases through the heat treatment mechanism that would bring the material to a harmless gas content and thus avoid the occurrence of flake defects or segregation cracks.

The primary heat treatment cycle is applied to the rolls after completion of forging respecting the diagram from figure 2.

Preliminary treatment parameters are calculated and correlated according to: steel grade, roll barrel size, remnant hydrogen content after vacuum and air cooling times.

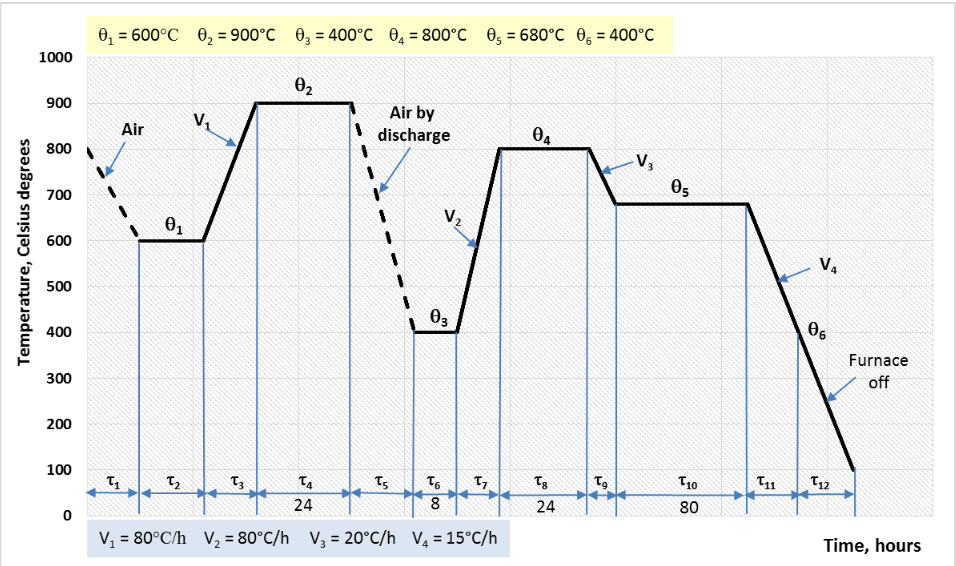


Fig. 2. Primary heat treatment cyclogram applied to rolls from 85 MoCrNi10 steel, after forging.

To determine the holding times, graphs are used that establish a dependency between the holding time, depending on the remnant hydrogen content and the diameter of the rollers, depending on the heating rate and diameter, as well as depending on the cooling conditions.
The temperature value θ_1 - θ_7 is given according to the steel used.
For 85MoCrNi10 steel rolls, these are:

θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7
600°C	900°C	400°C	800°C	680°C	400°C	100°C

and the heating and cooling speeds V_1, V_2, V_3, V_4 for rollers of 785 mm diameter, are:

V_1	V_2	V_3	V_4
80°C/hour	80°C/hour	20°C/hour	15°C/hour

Correlation and establishment of maintenance times was performed as follows:

τ_1 – represents the timed time corresponding to the cooling from the moment of removal from the last forging, until reaching and equalizing on the surface of the semi-finished product of temperature θ_1 (variable time depending on the real conditions of completion of forging and cooling after this operation). This time determines the maintenance in level τ_2, before the beginning of the primary heat treatment cycle;

τ_3 *şi* τ_7 - are the times related to the heats from θ_1 to θ_2 respectively θ_3 to θ_4 whose value is determined with the relations:

$$\tau_3 = \frac{\theta_2 - \theta_1}{V_1} \quad [h]$$

$$\tau_7 = \frac{\theta_4 - \theta_3}{V_3} \quad [h]$$

τ_5 – represents the timed time corresponding for air cooling of the rollers after austenitization, until reaching and equalizing on the surface of the temperature θ_3;

τ_6 – represents the equalizing time at temperature θ_3;

τ_4 – the holding time related to the temperature equalization in the section of the rolls and is established according to the heating speed V_1 and their maximum diameter;

τ_8 – the holding time afferent to the incomplete austenitization necessary to soften the material (spheroidization of carbides) and is determined according to the heating speed V_2 and the maximum diameter of the rollers;

τ_9 – the duration of directed cooling from θ_4 to θ_3 with V_3 and is determined by the relation:

$$\tau_9 = \frac{\theta_4 - \theta_5}{V_3} \quad [h]$$

τ_{10} – holding time at subcritical temperature to obtain softening of the material. It is determined according to the heating speed V_2 and the maximum diameter of the rollers;

τ_{11} – duration of maintenance at subcritical temperature related to dehydrogenation by heat treatment and this duration is established depending on the maximum diameter of the rollers and the residual hydrogen content;

τ_{12} – the duration of directed cooling from θ_5 to θ_6 with speed V_4 and is determined by the relation:

$$\tau_{12} = \frac{\theta_5 - \theta_6}{V_4} \quad [h]$$

Air cooling after austenitization is performed by unloading the rollers from the furnace, placing them on the cooling supports, then by wrapping the roll barrels with asbestos cloth, as soon as they reach temperatures θ_3 + 150°C. The cooling of the rollers is directed to obtain the equalization of the temperature θ_3 on their entire surface.

After the primary treatment, the rollers are processed to the established dimensions, being further subjected to the secondary heat treatment.

The analysis was done on a batch of 9 rolls, and the secondary heat treatment with oil cooling gave good results.

The secondary heat treatment is applied to the rollers after the roughing operation and aims to obtain a structure that confers the functional characteristics provided in the execution norms with minimum residual stresses.

Following several experiments, it was established that the thermal cycle given by the cyclogram in figure 3, having as main parameters the value of temperatures θ_1 - θ_7 as follows:

θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7
max.200°C	650°C	880°C	350°C	600°C	300°C	20°C

Their value level admits the following tolerances:

- at heating temperatures ±10°C;
- at cooling temperatures ±30°C.

For heating and cooling speeds, the recommended values are:

V_1	V_2	V_3	V_4
30°C/hour	40°C/hour	50°C/hour	25°C/hour

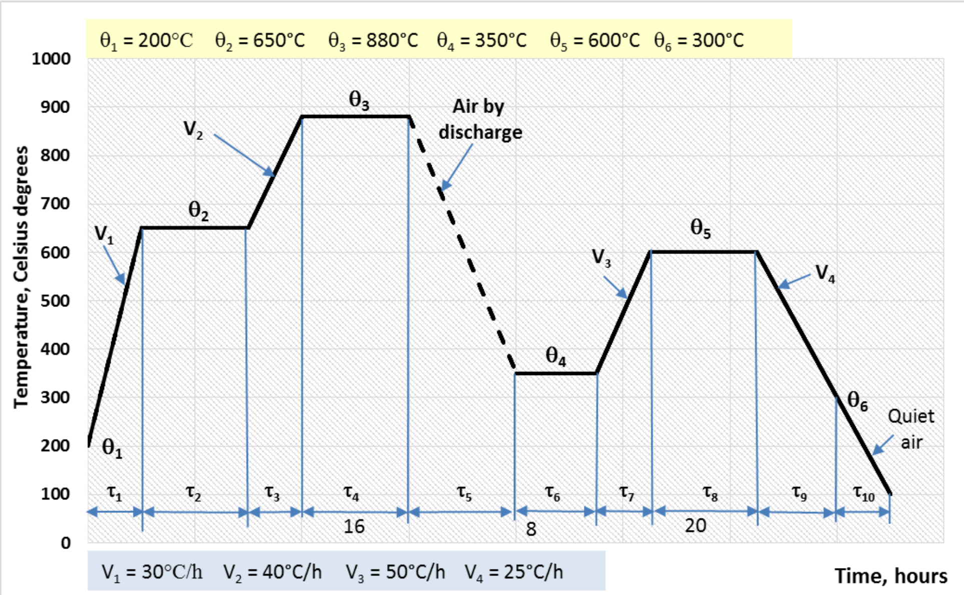


Fig. 3. Optimal cyclogram for secondary heat treatment applied to rolls from 85 MoCrNi10 steel.

The equalization duration is estimated at approx. 1.2h/100mm from the diameter of the roll barrel.

In order to obtain a lower hardness at the neck barrel than on the barrel, they were protected with asbestos cloth when the rolls were discharged when cooled in the air, after obtaining the quenching temperature.

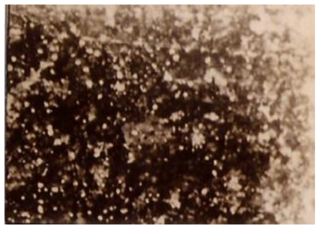
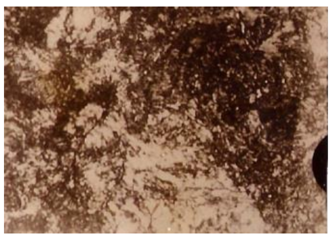
After performing the secondary heat treatment, samples were taken from each roller for qualitative and structural tests.

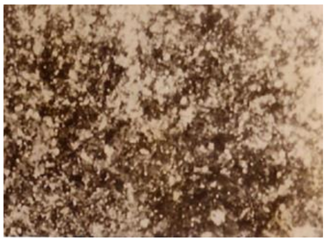
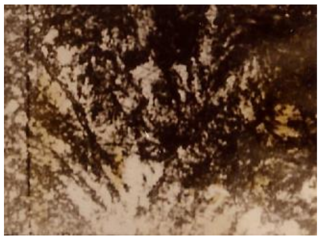
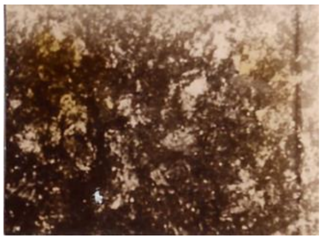
The analysis of the qualitative parameters in table 2 highlights the fact that one of the most important properties of steel is its hardening capacity. This property has a double importance: firstly for obtaining by heat treatment a higher hardness or resistance and secondly for achieving a high degree of toughness corresponding to the desired structure, finishing the granulation and obtaining a more favorable distribution and size of carbides than that obtained by forging.

In fact, achieving a high degree of toughness is the most important property, while achieving a strength can often be less important as long as it is not accompanied by sufficient toughness to cope with operating conditions.

The final microstructure and therefore the rollers properties depend both on the behavior during the austenitic transformation, as well as on the cooling conditions. If these two factors are known, the final microstructure can be predicted and even obtained by directing one of them or even both.

Table 2. The value of the qualitative and structural parameters resulting from the research of rolls made from 85MoCrNi10 steel grade

No.	**Thermal treatment**	**Mechanical characteristics**						**Structure after treatment Scale: 500:1**
		Yield strength, $R_{p0,2}$ $[N/mm^2]$	Tensile strength, R_m $[N/mm^2]$	Elongation, A [%]	Reduction in Area, Z [%]	Resilience, KCU $[J/cm^2]$	Hardness, HB	
1.	Quenching 880°C Tempering 600°C	943	1236	9	27,7	15	373	
2.	Quenching 880°C Tempering 610°C	752	1098	10	9,7	25	313	
3.	Quenching 870°C Tempering 610°C	625	1145	6	17,1	23	306	
4.	Quenching 870°C Tempering 610°C	650	1191	7	15,3	13	321	

5.	Quenching 880°C Tempering 610°C	803	1210	9	13,5	21	329	
6.	Quenching 870°C Tempering 600°C	573	1095	4	5,9	13	337	
7.	Quenching 870°C Tempering 620°C	601	1172	10	31,1	25	306	
8.	Quenching 870°C Tempering 620°C	623	1180	8	15,5	15	306	
9.	Quenching 880°C Tempering 620°C	650	1158	7	11,5	12	313	

Conclusions

The contributions brought through the experiments performed with 85MoCrNi10 steel grade consisted in raising the quenching temperature to 880°C, which allowed to obtain structures with a high degree of finishing and carbides evenly distributed in the base mass (no. 1,2,4,5,6 and 9 from table 3).

At the rollers with lower hardness (no. 3,7 and 8) resulted a structure with globular carbides in proportion of 20% and with slight network traces, which had the effect of a sensitive reduction of hardness.

It turns out that a quenching to 880°C followed by a tempering to 610°C, ensures a high hardness and a structure with fine carbides, evenly distributed in the base mass. This structure favors the obtaining of the best characteristics of mechanical and wear resistance, which satisfy the requirements of operation and increase of the durability of the rolling mill rolls.

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