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IMPROVING THE OPERATIONAL PROPERTIES OF CENTRIFUGAL CAST ROLLS WITH A WORKING LAYER OF CHROMIUM CAST IRON WITH MICROSTRUCTURE ASSESSMENT BY COMPUTER VISION

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Abstract. Based on the performed studies, it was found that the main criteria describing the quality and wear resistance of a roll with working layer of chromium cast iron are: proportion of residual austenite; degree of structure dispersion; chemical composition (ratios Cr/C, Ni/(Cr/C) and Cr/Ni); carbide phase; mechanical properties; voltage level regulated by heat treatment according to Hc. To predict operational resistance, it is advisable to use models establishing the relationship between chemical composition, ratio of structural components, conditions of working layer formation, heat treatment parameters, mechanical and operational properties.

Keywords. Wear resistance, friction, chromium cast iron, computer vision, watershed transformation.

1. INTRODUCTION

One of the main tasks of modern mechanical engineering is to ensure stable operational durability of products throughout the entire life cycle. As shown in [1, 2], especially significant difficulties arise in the production of large–sized products – rolls of rolling mills weighing up to 12–18 tons, where ensuring such stability during the manufacturing process determines obtaining high durability in operation [3, 4]. A rather complex process of stationary and centrifugal casting of large-sized rolling rolls [5, 6], which are unique products, provides not only for pouring the working layer (chrome-plated cast iron) and the core (gray or high-strength cast iron), but also several metal washings to increase the width of the transition zone, reduce thermal stresses, when cooling the product. In stationary casting, the variable composition of the charge requires flexible adjustment of the modifying treatment parameters to ensure uniformity along the length of the roll barrel and the cross section of the working layer [7].

Experimental work on the selection of optimal modes of modifying and heat treatment on rolls is costly [8]. In addition, full-scale tests are quite time-consuming: they require cutting the roll to conduct studies of the macro- and microstructure of the working layer, hardness distribution, determination of mechanical properties [9, 10]. Therefore, studies are carried out only on samples cut from the upper and lower edges of the barrel during roll machining. This does not allow them to be evaluated along the entire length and depth of the working layer of the product. In this case, an effective alternative is the use of a structurally sensitive magnetic characteristic – coercive force (hereinafter H_c) [11, 12], and for automating the assessment of structural components – metallography methods using computer vision technologies.

To ensure high operational durability of massive castings from cast iron in rolling production conditions, a rational selection of material composition, modification, heat treatment parameters is used, taking into

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account operating conditions, their execution and standard sizes based on magnetic control indicators.

The most promising material for the working rolls of the finishing stands of sheet mills is alloyed chromium cast iron. However, it is not effective to make a single-layer roll of large mass from it due to the low manufacturability of the material and the increased cost of alloying elements. Therefore, it is expedient, and recently an increasingly common process, is the manufacture of double-layer rolls by the centrifugal casting method.

The aim of work is to improve the operational properties of centrifugal cast rolls with a working layer of chromium cast iron with assessment of the microstructure by computer vision.

2. MATERIALS AND METHODS

Alloys composition was determined by chemical (C, O, N) and spectral (Mn, Cr, Si, P, Ni, Cu, Al, Ti, Mo) methods, and also refined by X-ray microanalysis.

Study of the microstructure was carried out on micro-grinders and directly on massive castings – rolls (Figure 1), after surface preparation, on a metallographic microscope MIM–8M and portable TCM at magnification ×100, ×200, ×500, ×1000. Proportion of residual austenite was assessed using a specially developed method metallographically, as well as by the magnetic method on MK–59 and MA–52 devices. The analysed surfaces were etched with a 4% solution of nitric acid (HNO_3) in ethyl alcohol.

Figure 1. Centrifugal cast rolls with a working layer of chromium cast iron.

The wear of materials was assessed by testing the disks with a diameter of 6 mm under friction under a load of 9.8 MPa, which made it possible, due to the small contact area, to provide pressure in the surface layer up to 350–400 MPa. At the same time, the temperature of the disk imitating the rolled metal was 800±20 °C, and the test material was 40–45 °C.

Thermal endurance tests were carried out on pinched samples, which provided the specified alternating stresses, which were controlled as in standard mechanical tests. Number of cycles before the destruction of sample was taken as thermal endurance, which was recorded automatically. The cycle time was 35 s (heating 30 s, cooling 5 s). Registration of thermal stresses arising in the sample during cyclic processing was recorded by a recording potentiometer.

Measurements in production conditions were carried out using portable coercitimeters КРМ–Ц with two types of overhead converters. Content of residual austenite was assessed by MA–52 device. The limit of device permissible absolute error readings is up to 10%. The measurement methodology is presented in the industry standard of Ukraine developed by us (SOU 29.32.4-37-532 :2007), taking into account the individual characteristics of a particular technological process and product, makes it possible to effectively improve not only the mechanical, but also the operational properties of products based on an assessment of their structural condition and correction of manufacturing and processing processes.

Cracks on the working surface of the rolls after operation.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The high quality of rolls with a working layer of chrome-plated cast iron is determined not only by the achieved structure, hardness and strength of the working layer metal, but also by their uniformity. Uniformity of properties along the length and perimeter of the sheet roll barrel ensures consistently high quality of rolled metal. The appearance of zones with differing hardness leads to uneven roll development and the development of different thicknesses on the produced rolled metal. Heterogeneity of properties along the length and barrel of the roll can be caused by various reasons. Which may include: uneven heat dissipation of the crystallizing metal of the working layer; presence of liquation phenomena; formation of local stresses.

All of these factors can occur during casting crystallization, and the appearance of the latter is also possible if the technological process of heat treatment is disrupted.

The uneven heat sink of the crystallizing metal can be determined by the difference in the coating thickness. At the same time, the metal structure will change significantly (proportion and distribution of the carbide phase, amount of austenite). In areas with a high proportion of carbides, the hardness will be higher. Readings and NS will react to such a change in structure, as well as hardness. In this case, values with deviations from the established optimal limits will appear.

The presence of liquor phenomena can also contribute to significant structural changes. The degree of structural heterogeneity is determined by the concentration of basic, alloying additives and modifiers. Accumulation of carbides, as well as non-metallic inclusions is possible. This will also have an impact on the testimony of H_c.

Uneven heat dissipation during crystallization and heat treatment, which cause localization of stresses, do not contribute to significant structural changes, however, they affect the stress-strain state of the product (Table 1). With its growth, the level of H_c increases. Traditional heat treatment, without taking into account the stress-strain state, does not allow providing the necessary level of mechanical and operational properties. In some cases, the stress level after such treatment not only does not decrease, but also increases by 15–20%.

Thus, deviations in the readings of H_c are the result of three effects: non-homogeneous structure (its local change) during crystallization, liquation phenomena and localization of stresses. To determine the causes of the observed deviations in the readings of H_c at the place of measurement, non-destructive testing of the metal structure was carried out, and then a decision was made to carry out repeated heat treatment and its parameters.

A statistical analysis of the changes in H_c along the length and perimeter of the rolls was performed and the conclusions were confirmed that repeated heat treatment, taking into account the initial level of the stress-strain state, increases the uniformity of properties.

In the production of rolls, metal was smelted in an electric furnace with overheating up to 1530–1550 °C and brought to a given chemical composition. The metal for the roll necks core was smelted in an induction furnace and released in two buckets of 7.5 tons at 1460 °C. Ligature and fluorspar were added to the buckets. Simultaneously with the release of metal, a centrifugal machine was launched.

After cleaning the metal surface from slag in the bucket and measuring the temperature, the working layer was poured at a temperature of 1380–1420 °C. In the first 8–12 seconds, the volume of the poured metal is underestimated, and the rotation speed of the machine is 465–470 min^{-1}. The mass of the poured metal was determined taking into account the depth of the working layer on the roll after finishing 45–50 mm.

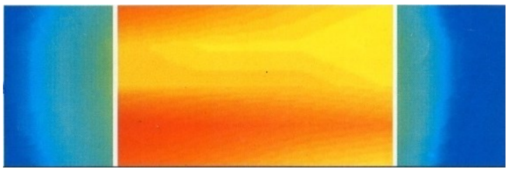
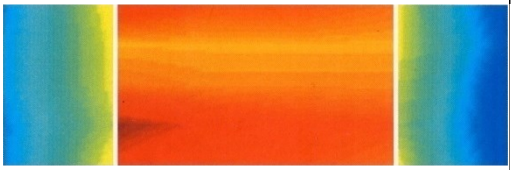
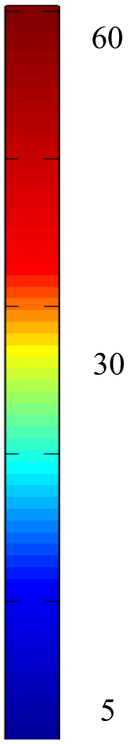
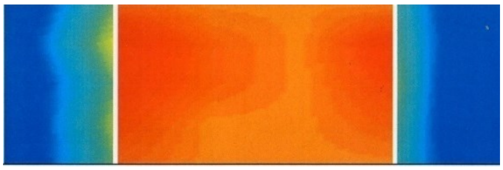
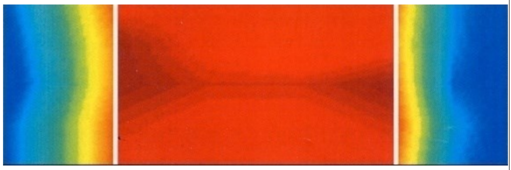
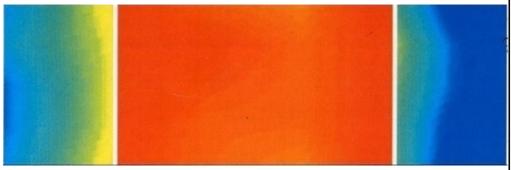
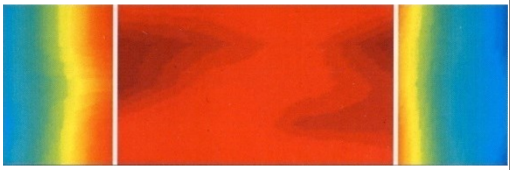
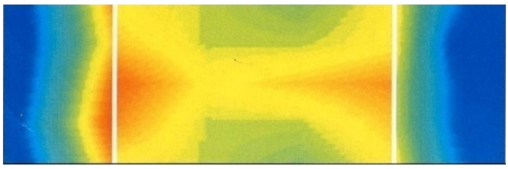
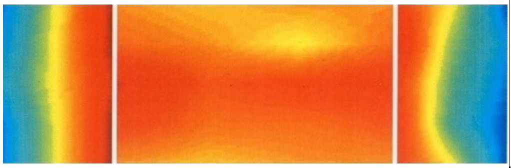
Position of the gate system was set at the level of 200 mm below the edge of the insert with a seal in the socket.

To form the transition zone, the first portion of the core metal was poured at 1310–1320 °C and the rotation speed of the machine was reduced to 450 min^{-1}.

After holding the intermediate layer for 4–5 minutes, the remaining metal of the core of the first bucket was poured. During this filling, the rotation speed was reduced to 350 min^{-1}. Filling of the second bucket was started at the same rotation speed, and then in the next 2–2.5 minutes it was reduced to 150 min^{-1} and then – after 1–1.5 minutes – to 50 min^{-1}.

After holding the intermediate layer for 4–5 minutes, the remaining metal of the core of the first bucket was poured. During this filling, the rotation speed was reduced to 350 min^{-1}. Filling of the second bucket was started at the same rotation speed, and then in the next 2–2.5 minutes it was reduced to 150 min^{-1} and then – after 1–1.5 minutes – to 50 min^{-1}.

Table 1. Distribution of H_c Level Across the Roll Barrel and Necks.

Conditional No. of the Roll	**Uniformity of H_c Distribution**						**Scale of Color Correlation to H_c Level, A/cm**
	after casting			**after traditional heat treatment**			
	neck	**barrel**	**neck**	**neck**	**barrel**	**neck**	
1							
2							
3							
4							

When the machine was stopped, the profit was topped up to a height of 250–300 mm below the upper cut of the mold, then it was insulated. After 20–25 minutes, the profit was topped up.

The cooling time of the roll was at least 96 hours in the caisson.

Studies of the operational resistance of centrifugal cast and stationary cast double-layer rolls of chromium-nickel and high-chromium cast iron were performed for roll diameters Ø900×2000 mm, Ø815×2300 mm, Ø820×2000 mm. Rolls were used in various designs (Table 2) in total, 170 rolls with a working layer of high–chromium cast iron – SHCr17NiMoTLC and 200 stationary cast – SHCrNiMoTL, SHCrNiTL were in operation.

The analysis of operational durability showed the following, that 900×2000 mm rolls of SHCr17NiMoTLC–63 (operating time 190623 t/roll) and SHCrNiTL –63 (operating time 180932 t/roll) have the highest average wear resistance. At the same time, the first did not develop a working layer, and the second ≈35% of the total number of rolls used (26 pcs.) exhausted it. These compared rolls have minor breakdowns (1–2 pieces), detachments (1–2 pieces), cracks (2–3 pieces), however, the number of rolls with a height grid for these versions is 9–11 pieces (Figure 1). In stationary cast rolls during operation, the proportion of rolls that have failed due to discoloration increases (7 pcs.), which is associated with coarser cementite-type carbides in them.

The surface of the barrel of rolls with cracks have several components (Figure 2): cracks (red colour); microcracks of different localization (green, azure, black color); working surface (blue color); strain hardening (yellow color). The threshold value was set for the local minimum to alleviate phases creation of catchment basins. The random walker algorithm resolves the segmentation [13] of images of the barrel of rolls with cracks from a set of markers labelling 6 components for surface. An anisotropic diffusion equation is explained with tracers begun at the markers' position. The local diffusivity number is greater if neighbouring pixels have similar values. The label of each unknown pixel is coupled to the label of the known marker [14]. That has the highest probability to be reached first during this diffusion process [15]. The images denoise using the non-local means filter [16]. The non-local means algorithm replaces the value of a pixel by an average of a selection of other pixels values: small patches centered on the other pixels are compared to the patch centered on the pixel of interest, and the average is performed only for pixels that have patches close to the current patch [17]. As a result, this algorithm can restore The surface of the barrel of rolls with cracks have several components (Figure 1): cracks (red colour); microcracks of different localization (green, azure, black color); working surface (blue color); strain hardening (yellow color). The threshold value was set for the local minimum to alleviate phases creation of catchment basins. The random walker algorithm resolves the segmentation [13] of images of the barrel of rolls with cracks from a set of markers labeling 6 components for surface. An anisotropic diffusion equation is explaining with tracers begun at the markers' position. The local diffusivity number is greater if neighbouring pixels have similar values. The label of each unknown pixel is coupled to the label of the known marker [14]. That has the highest probability to be reached first during this diffusion process [15]. The images denoise using the non-local means filter [16]. The non-local means algorithm replaces the value of a pixel by an average of a selection of other pixels values: small patches centered on the other pixels are compared to the patch centered on the pixel of interest, and the average is performed only for pixels that have patches close to the current patch [17]. As a result, this algorithm can restore

Table 2. Average Roll Resistance and Reasons for Decommissioning.

Rool Designation	Size, mm	Chips	Cracks	Breakdowns / Detachments	Grid Cracks	Average Roll operating time	Total number of rolls examined
Centrifugal Cast							
SHCrNiMoTLц–73	820×2000	5	2	–/8	2	153800	37
SHCr17NiMoTLC–58	900×2000	1	1	–/2	1	139738	14
SHCr17NiMoTLC–63	900×2000	2	3	1/2	9	190623	38
SHCr17NiMoTLC–63	820×2300	–	1	–/–	2	140194	6
Stationary Cast							
SHCrNiTL–63	900×2000	7	2	–/1	11	180932	75
SHCrNiMoTL–73	820×2000	8	–	2/32	9	140980	110
SHCrNiMoTL–73	820×2300	2	–	1/3	15	147335	90

Sheet-rolled high-chromium, chromium-nickel, chromium-nickel-molybdenum double-layer centrifugal cast roll.

The rolls of the centrifugal casting of SHCrNiMoTLC–58 version is characterized by a low tendency to breakage (they are absent), peeling, coloring, cracks, formation of heat grid (1 roll for each type of damage). With an increase in the roll's hardness (up to 73 HSD) both centrifugal castings and stationary ones noticeably increase their tendency to detachment (8 and 35 pcs. respectively), coloring (5 and 10 pcs.), forming the height grid (2 and 24 pcs.). Centrifugal cast rolls, in comparison with stationary cast rolls, in most cases are modified to natural wear.

Analysing the indicators of operational tests of rolls, it is necessary to note the following. Despite the lower hardness values (by 10 HSD), centrifugal cast rolls (Ø815×2000 mm) with a working layer of high-chromium cast iron are not inferior in operating time to stationary cast. Centrifugal cast rolls Ø900×2000 mm in comparison with stationary cast rolls with a hardness of 63 HSD and 73 HSD, respectively, have a 5.3–10% greater operating time, which is largely determined by the greater and homogeneous depth of the working layer.

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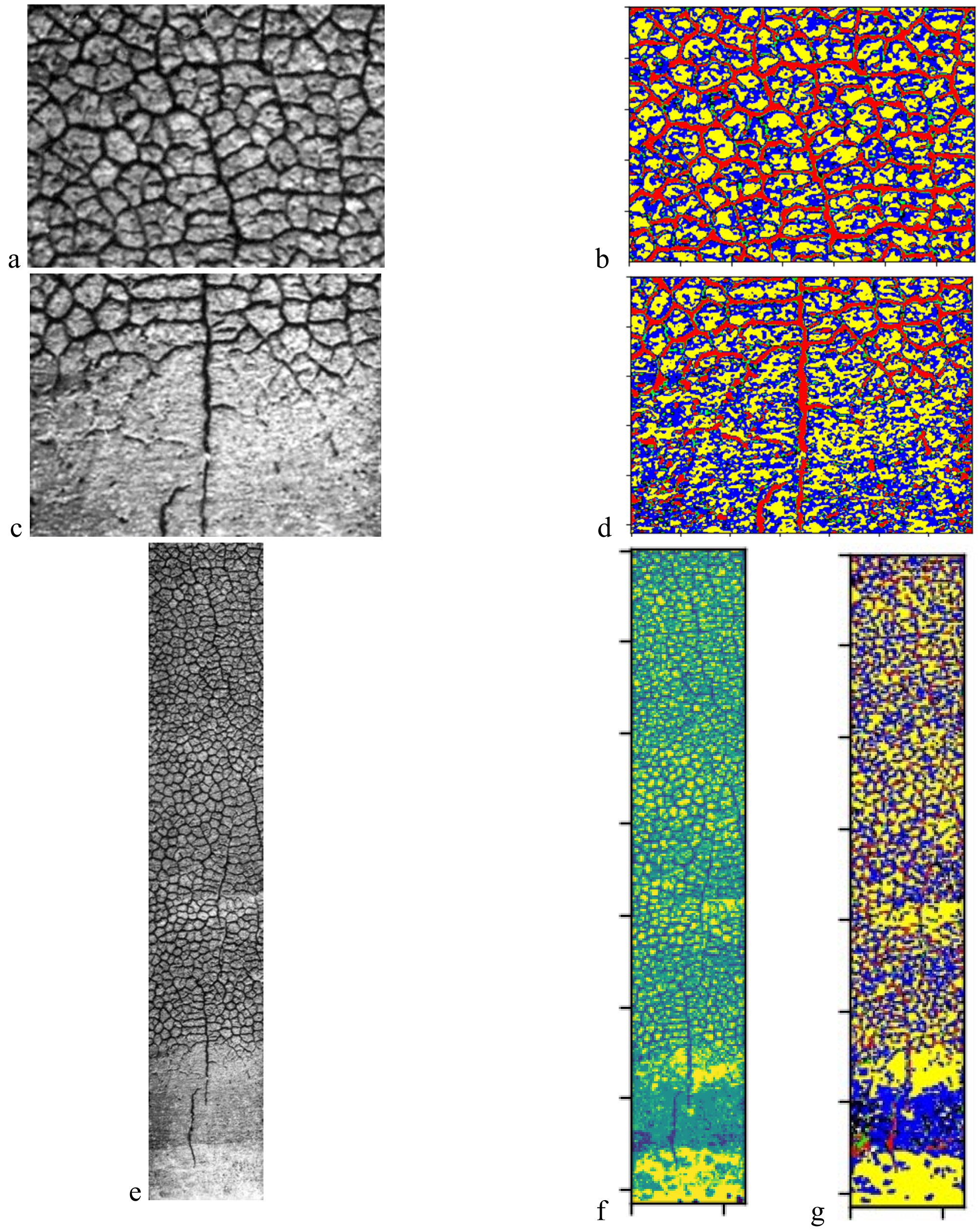

Figure 1. Illustration of the marker-based watershed segmentation workflow on a 2D image of microstructure of surface of the barrel of rolls with cracks: a) the gray-level structure of surface of the barrel of rolls with cracks, ×50; b) the segmented image with regions resulting from the marker-based watershed segmentation of surface of the barrel (the color corresponds to the segment), ×50: c) the gray-level structure of surface of the barrel of rolls with cracks and work hardening zone, ×50; d) the segmented image with regions, ×50; e) division of the working surface of the barrel of rolls, ×10; f) markers image after exposure (labeling 6 components of phases); g) the segmented image with regions of the working surface.

Formation of special carbides of the type $(Cr,Fe)_7C_3$ in high-chromium rolls excludes a decrease in strength in the temperature range of 150–250 °C (typical only for the temperature of magnetic transformation of cementite). The critical points of high-chromium cast iron are 50–100 °C higher than those of chromium-nickel, which reduces the tendency to phase transitions on the working surface in contact with hot metal. All these advantages also provide higher operational resistance of high-chromium cast iron.

Evaluation of operational durability showed that the two-layer rolls, written off as a result of natural wear, have high resistance, on average 6300 t/mm of removal of the working layer. Number of rolled products per roll reaches 315–464 thousand tons (on average 382 thousand tons). These indicators are 1.5 times higher than the performance characteristics of chromium-nickel rolls (on average 244 thousand tons) with a resistance of 4145 t/mm.

Analysis of operational characteristics was carried out for a sample of 52 rolls. Results are presented in Table 3.

Painting of the rolling rolls working surface is one of the reasons for their premature overfilling. During operation, the rolls are subjected not only to thermocyclic loading, but also to the action of high specific pressures (up to 3 t/mm^2). At the contact sites, different voltages occur in magnitude. At some points of the contacting surfaces, intense plastic deformation occurs, activating diffusion processes and structural changes in the surface layers, formation of films, oxides and chemical compounds, formation and destruction of setting nodes.

In this regard, the following requirements are imposed on them: ensuring the necessary hardness and the ratio of structural components; strength; low tendency to staining and plastic deformation.

The main ways to implement these requirements are: optimization of chemical composition, improvement of roll manufacturing technology and improvement of their operating conditions.

A significant increase in roll resistance can be achieved by optimizing the chemical composition.

The dependences of the operational properties of roll working layer made of high chromium cast iron on the Cr/C ratio were established for the sample of 52 rolls:

$$U_{av.op} = 1603\ Cr/C - 5249, \tag{1}$$

where $U_{av.op}$ is the average operating time of the rolls per millimeter of removal of the working layer, t/mm.

$$U_{res.crack} = 51.4\ Cr/C - 129.9 \tag{2}$$

where $U_{res.crack}$ is the resistance to cracking in operation, thousand tons.

On the one hand, the carbon content in high-chromium cast iron should not be high, since its increase is associated with an increase in the carbide phase proportion and dyeing process intensification. Increase in the content of chromium, as well as other carbide-forming elements, on the contrary, reduces the tendency of cast iron to staining.

On the other hand, an increase in the Cr/C ratio leads to increase in the degree of structure dispersion, which is a favorable factor in terms of increasing the operational properties of rolls operating at high temperatures. Thus, with a decrease in the size of the carbide grain from 75–85 µm to 50–55 µm, the durability of the working layer increases:

$$U_{av.op} = 15320 - 150\ d_{carb}, \tag{3}$$

where d_{carb} is the average size of the carbide grain of the working layer, µm.

With an increase in the Cr/C index, the ratio of the phases of the metal matrix and their resistance to plastic deformation changes. Also, increase in the chromium content in cast iron from 12.2 to 18.1% leads to increase in the proportion of special carbides of the type $(Cr,Fe)_7C_3$, and finely dispersed secondary carbides $(Cr,Fe)_{23}C_6$ in the structure, which provide higher wear resistance of the working layer.

Table 3. Distribution of H_c Level Across the Roll Barrel and Necks.

Conditional Roll No.	**Operational Characteristics**							
	D_{initial}, mm	**D_{final}, mm**	**Number of re–rolls**	**Rolling, t**	**Taking-off on 1 roll, mm**	**Resistance of the working layer, t/mm**	**Resistance of the working layer, t/per.**	**Condition**
1	814.1	800.2	21	70098	0.66	5043	3338	cracks
2	816.2	760.0	5	11578	1.24	206	2316	cracks
3	811.8	800.2	21	70098	0.55	6043	3338	cracks
4	817.6	760.0	111	235222	0.52	4084	2119	cracks
5	820.2	819.2	3	11239	0.33	11239	3746	shells
6	818.8	760.0	109	231323	0.53	3961	2122	cracks
7	822.6	776.0	20	58213	0.30	1249	2911	cracks
8	913.5	906.6	22	53388	0.31	7737	2427	cracks
9	815.5	779.3	28	69074	1.29	1908	2467	detachment
10	812.7	762.0	34	75973	1.23	1498	2235	cracks
11	816.5	789.6	35	98242	0.50	3652	2807	operation*
12	819.4	817.4	4	10988	0.50	5494	2747	cracks
13	813.0	777.7	42	103179	0.86	2923	2457	cracks
14	812.2	811.3	5	15797	0.18	17552	3159	cracks
15	809.6	760.0	53	124411	0.94	2508	2347	natural wear
16	819.1	815.0	13	31082	0.32	7581	2391	operation*
17	815.0	803.1	33	87770	0.36	7388	2660	operation*
18	913.0	860.0	29	70800	0.32	1336	2441	scrapp. on the neck
19	819.5	760.0	155	372106	0.36	6254	2401	natural wear
20	811.2	762.0	164	352000	0.30	7154	2146	operation*
21	818.7	800.0	9	26794	2.08	1433	2977	operation*
22	822.9	804.5	16	42882	0.40	2331	2680	cracks
23	909.0	859.2	151	315291	0.33	6331	2088	natural wear
24	813.3	811.7	5	15797	0.32	9873	3159	cracks
25	819.1	815.0	12	30317	0.34	7394	2526	operation*
26	819.9	817.7	4	10988	0.55	4995	2747	cracks
27	810.2	809.2	4	11776	0.25	11776	2944	cracks
28	809.6	808.3	4	5022	0.32	3863	1256	operation*
29	813.0	808.1	8	26509	0.61	5410	3314	scrapp. on the barrel
30	812.6	782.0	45	109049	0.50	3564	2423	cracks
31	811.5	760.0	65	154207	0.81	2994	2372	cracks
32	815.0	787.8	68	172928	0.40	6358	2543	on the club
33	813.0	805.4	14	48984	0.54	6445	3499	operation*
34	811.1	773.3	57	120049	0.68	3176	2106	cracks
35	911.0	900.8	33	71227	0.31	6983	2158	on the club
36	914.0	860.0	15	33018	3.60	611	2201	cracks
37	911.0	848.9	207	464255	0.30	7476	2243	natural wear
38	810.1	805.0	13	38534	0.39	7556	2964	cracks
39	810.0	803.0	14	48984	0.50	6998	3499	on the club
40	815.3	807.0	21	66776	0.40	8045	3180	cracks
41	904.0	860.0	44	87618	1.00	1991	1991	cracks
42	915.2	860.0	95	206110	0.51	3734	2170	cracks
43	913.0	907.5	20	48880	0.28	8887	2444	cracks
44	819.7	813.5	13	38572	0.47	6221	2967	cracks
45	818.8	776.0	17	49262	0.44	1151	2898	cracks
46	818.5	809.5	6	19384	1.50	2154	3231	cracks
47	900.0	860.0	93	209893	0.37	5247	2257	cracks
48	915.0	839.4	180	386757	0.42	5116	2149	natural wear
49	817.8	800.0	21	66776	0.47	6814	3180	cracks
50	813.3	810.7	9	25195	0.29	9690	2799	cracks
51	664.0	662.9	1	2186	1.1	1987	2203	scrapp. on the barrel
52	909.0	877.0	31	68296	1.03	2134	2186	on the club
53	914.0	902.9	33	71227	0.34	6417	2158	on the club
54	818.8	760.0	155	372106	0.35	6328	2401	natural wear
55	910.0	908.8	3	4377	0.40	3648	1459	on the club
Note: * Operational tests are ongoing								

Studies on the optimization of high-chromium cast iron have chemical composition shown that reliable operation of the rolls is possible if the Ni content is limited in it. It was found that the best crack resistance indicators were obtained for the ratio Ni/(Cr/C)<0.22. Increase in this ratio of more than 0.28 leads to a sharp deterioration in resistance indicators:

$$U_{res.crack} = 784 - 2420\ Ni(Cr/C) \tag{4}$$

$$U_{av.op} = 61 - 488\ Cr/Ni \tag{5}$$

Change in silicon (from 0.33 to 0.98%) and molybdenum (from 0.58 to 1.37%) content has no noticeable effect on the operational properties of the roll working layer.

The intensity of thermal crack formation process under conditions of thermal cyclic loading largely depends on the level of residual compressive stresses. However, too high stress level or their unfavorable distribution along the perimeter and length of the roll can cause premature destruction of the working layer.

To assess the stress state directly on the roll, the measurement of H_c was used as an express method.

As the statistical analysis of the operation data showed, the level of coercive force should not exceed 42 A/cm. In this case, satisfactory indicators of wear resistance and tendency to cracking are provided:

$$U_{res.crack} = 1080 - 23{,}3\ Ni(Cr/C) \tag{6}$$

$$U_{av.op} = 180 - 32\ H_c \tag{7}$$

Ensuring an optimal phase ratio and a balanced distribution of residual stresses can be ensured by a properly selected heat treatment mode. When developing the technological process of heat treatment, results of temperature fields, estimates of generated stresses calculations were taken into account.

Based on theoretical and experimental studies, it has been established that the heating and cooling rate should not exceed 10–15 °C/h, and the annealing exposure should be at least 5–7 hours (at the rate of 1 hour per 25 mm of the roll radius). When heat-treating massive rolls (10–12 t), the use of such a heating and cooling rate can be effective with the introduction of additional exposure stages to equalize the temperature along the roll section.

It is recommended to perform annealing according to the following modes:

– for rolls with a Cr/C ratio < 5, in the structure of which the minimum amount of residual austenite is cyclic heat treatment (2 cycles) according to the two–stage heating mode up to 450±10 °C. Heating to a temperature of 200 °C at a speed of 10–15 °C/h. At 200±15 °C exposure in the oven is 2 hours. Further heating up to 450±10 °C a speed of 10–15 °C/h and an exposure time of 6–10 hours (depending on the diameter of the roll) to equalize the temperature along the cross section of the roll. Cooling should be carried out at a speed of 10–15 °C/h with a stop at 200±15 °C – exposure time of 2 hours. Second heating cycle up to 450±10 °C is carried out according to the same mode. Cooling after a two-stage cycle with 200±15 °C – with the oven turned off during the day;

– for rolls with a ratio of Cr/C>5 – cyclic heat treatment (2 cycles) according to the two-stage heating mode up to 500±10 °C. Heating to a temperature of 200±15 °C with a speed of 10–15 °C/h. At 200±15 °C exposure in the oven – 2 hours. Further heating up to 500±10 °C with a speed of 10–15 °C/h and an exposure time of 6–10 h to equalize the temperature along the cross section of the roll. Cooling should be carried out at a speed of 10–15 °C/h with a stop at 200±15 °C – exposure time of 2 hours. Second heating cycle up to 500±10 °C is carried out according to the same mode. Cooling after a two-stage cycle with 200±15 °C – with the oven turned off during the day.

Such treatment will ensure the decay of residual austenite up to 2–4% and a reduction of stresses up to 2 times.

4. CONCLUSIONS

The use of rolls with a working layer of high-chromium cast iron on the finishing stands of broadband mills ensured an increase in their durability by 1.5 times. Such increase in operational durability is achieved by providing, estimated by H_c, a homogeneous structure along the cross-section of the working layer, its grinding at a certain ratio of components in cast iron due to the recommended heat treatment parameters.

It is shown that the optimization of the chemical composition of high-chromium cast iron achieves the grinding of the carbide phase, a decrease in the proportion of residual austenite, increase in strength and decrease in the tendency to cracking. Dependencies are proposed that allow evaluating operational properties: resistance to cracking ($U_{res.crack}$), thousand tons ($U_{res.crack}$=1083–23.3 H_c) and the average operating time of the working layer of the rolls ($U_{av.op}$), t/mm ($U_{av.op}$=178–32 H_c).

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