The development of non-destructive quality control of massive castings

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Abstract
Modern requirements to quality of the rolled sheet are provided by operating indexes and reliability of work of roll. As a result of exploitation fatigue stress are formed in a working layer. Their accumulation reduced reliability of roll. It stress-deformed condition is a result of chemical, physical and structural changes in a working layer, that flow with different intensity along all rolls surface. According to the requirements of international standards of products certification, modern analysis of rolls quality is a complex control of their condition at every stage of production that includes different methods: chemical, structural, physical, determination of mechanical properties etc. Traditionally they are carried out on specially selected samples from billets by means of modern equipment. However, control with their means does not allow estimating the stresses condition along all working surface of roll and cannot be used for the operative analysis of products quality, which intended for exploitation. The non-destructive method of qualities control by means of portable coercimeter for the operative estimation of current rolls condition has been proposed at the paper. The aim of this paper was a study by means of measuring of coercitivity of quality of working layer of the sheet-rolling rolls that are poured by centrifugal method. Experimental researches showed that heterogeneous distribution of hardness values along the rolls barrel raises the level of coercitivity. It is determined that its increase proportionally of hardness dispersion along a working surface. It is connected with peculiarities of solidification of massive roll of complicated-alloying melts at field of centrifugal forces action.

Keywords: CAST IRON, CENTRIFUGAL CASTING, CHEMICAL COMPOSITION, COERCIVE FORCE, HARDNESS, MAGNETIC METHOD, MASSIVE ROLL, STRESSES, STRUCTURE, WORKING LAYER

Introduction

Modern requirements to the quality of the rolled sheet may be provided with only the exploitation parameters of roll and increase of its operation intensity. In multistand mill roll is moved from finishing operation to roughing stand by decrease of its working layer [1, 4, and 10]. According to the rolling technology for each stand speed of process and nominal thickness of metal product are strictly regulated. At the same time loading distribution on roll change within 10 percent of nominal value, which leads to displacement of stresses peak in the forming tool. Standard roll data sheet does not contain information about preliminary stress-deformed condition of the product. As a result of roll profiling is performed without its taking into account that they may contribute stress accumulation and premature destruction of the working layer.

Thus the actual task for rolls manufacturers is control of their current stress-deformed condition both during manufacture and at exploitation.

It is known [1, 4, 8, 9] that formed in the working level of inside stresses is the result of chemical, physical and structural changes, which flow with different intensity along roll during production (casting, machining and heat treatments).

But stress state of the two-layer polycrystalline body roll changes. Process of redistribution and alignment of stresses upspring inside the body. It leads to stresses relaxation. There is some smoothing local structure distortion and uneven stresses. This process is accompanied by total deformation of solid. There are cases of following destruction, such as cracking. So important is the knowledge or idea of the order of value of the internal stress and the nature of it change. This is achieved by using only measurements.

In according with requirements of international standards of product certification modern analysis of rolls quality is complex control of their condition at every stage of manufacture that includes various methods: chemical, structural, physical, determination of mechanical properties etc. They are carried out on specially selected from billets samples through modern equipment. But destructive methods of quality control are rather expensive and time-consuming processes. Besides its use is limited by small size of working layer of roll and its high hardness. They are difficult for operative analysis of stress condition along the working surface of the roll, which intended to exploitation.

Analysis of recent research and publications

Non-destructive methods have been developed for operative control of current condition of oversize rolls. They are based on different physical effects [5, 6]. The search of inside defects and discontinuities in products body and determination of size of working layer along the entire surface is fulfilled by means of ultrasonic control through detector of UD 42T type. Research of structure and of hardness level along products surface is performed with the help of portative devices: microscope, hardness unit Shore, «EQUOTIP», «Elite» [5]. However their application is complicated during control of roll casting quality, which differs with considerable surface roughness $(R_Z = 500)$.

Magnetic methods of non-destructive control ensure receipt of sufficient information about the structure, physical and mechanical properties and stress-deformed condition of sheet rolling rolls of different types and sizes [2, 3, 5, 7, and 9]. The basis of their use is the observed community of structural influence at magnetic (magnetization M_s, coercive field H_c, residual magnetization M_r, etc.) and mechanical properties. It has been established that the most structure sensitive characteristic is coercive force H_c [4]. Experimental researches of distribution of coercive force values at surface of rolls are realized according to the developed method [4] through the automated instrument KRM-C, which is a portative compound measuring device and contain U-shaped magnetizing apparatus, electronic indicated unit and reference scale of values coercive force [3, 9]. The value of coercive force ranges from 1.5 to 55 A/cm. It is determined by angle of magnets rotation. Its zero value depends of magnetic stream. The magnetic stream is controlled by Hall sensor, which is mounted in magnetic wire of coercimeter. Zero value of magnetic stream is indicated by flashing light-emitting diode.

Reservedly portative structuroscope KRM-C indications of coercive force distribution ensure estimation of stress-deformed condition rolls and establishment their correlation with structural changes, which flow in casting. Local zones with raised values of the coercive force are established as addition to surface measuring of hardness. It is possible to envisage formation of crack and crumbling of working layer [4].

That is why the **aim of this paper** is the study of quality of the massive centrifugal casting rolls working layer by using measuring the coercive force.

For improvement of this aim solved such **problems**:

- to estimate change of coercive force value along working surface for rolls with different hardness level;
- to research influence of cast iron chemical composition and conditions of working layer crystallization at formation of hardness and stresses level;
- to conduce metallography analysis of working

layer microstructure of researched rolls.

Basic material for research

Researches of uniformity of hardness and coercive force distribution along surface was carried out on more than twenty centrifugal casting rolls with working layer of chromium-nickel-molybdenum cast iron, which contains the following components: 3,06-3,44 % C; 0,85-1,2 % Si; 0,76-1,1 % Mn; not more than 0,13 % P and 0,03 % S; 1,7-1,9 % Cr; 4,2-4,6 % Ni; 0,32-0,49 % Mo. Portative devices - measuring hardness unit Shore and coercimeter KRM-C was used for experiments.

Researched castings were characterized by different level of properties: hardness ranged 72-77 HSD and the coercive force - 15-30 A/cm (Table 1).

The table 1 shows that the level of coercive force is directly proportional to the hardness, which is agreed with previous researches [4].

Analysis of castings with the same level of the working layer hardness showed that the non-uniform distribution along its roll barrel greatly increases the coercive force (figure 1).

Table 1. The dependence of the coercive force level of hardness distribution uniformity along working layer of analyzed rolls

No group	Quantity of castings, pcs	Hardness, HSD		Coercive force H_c, A/cm	
		middle value	dispersion of indications s^2	middle value	dispersion of indications s^2
1	2	72	0	16	1,7
2	1		0,5	18	0,28
3	1		2	19	0,989
4	2		4,5	25	0,9
5	1	75	0	20,2	0,62
6	2		0,5	22,8	0,5
7	1		2	24,1	0,964
8	1		4,5	27,6	0,5
9	1	77	0	24	0,851
10	4		0,5	26	1,1
11	4		2	28	0,4
12	3		4,5	31	0,267

For all analyzed rolls with fixed level of hardness dispersion its value and increasing of coercive force are proportional:

$s^2_{HSD} = 0{,}5$ – $\Delta H_c = 2\ A/cm$; $s^2_{HSD} = 2{,}0$ – – $\Delta H_c = 4\ A/cm$; $s^2_{HSD} = 4{,}5$ – $\Delta H_c = 8\ A/cm$.

Deviations at coercive force indications of optimal limits are determined of three phenomenons:

– the non-uniform distribution of structural components, which formed at crystallization process of metal;

– presence of separation phase, which is typical for centrifugal casting, (including accumulation of non-metallic inclusions);

– localization of stresses, which are arisen at process of non-uniform heat extraction during roll solidification of complex-alloyed melt.

Results of researches [4] shows that quantity correlation of structural components at working layer metal, it distribution depend on chemical composition and crystallization speed.

According to it the influence of chemical composition of cast iron and condition of crystallization at formation of hardness and stresses were researched.

Rolls were studied for realization of experiment. Temperature of working layer pouring and duration of standing between it and core alloys were fixed. Chemical composition of chromium-nickel-molybdenum cast iron and value of heat insulated coating ($h_c = 3.25 - 3.45\ mm$) were changed. h_c estimates process crystallization of cast iron.

Joint influence of chemical components at researched cast iron was expressed by extent of eutectic

$$S_e = \frac{C}{C_c + \Sigma k_i C_i}, \qquad (1)$$

where C – carbon content in alloy, %; C_c – carbon content in eutectic (C_c =4,26%); C_i – content of other elements in the alloy; k_i – coefficients of its influence intensity at concentration of carbon.

Extent of eutectic for researched alloys changed between 0.77-0.86.

Next mathematic model have been taken by method of experiment plaining:

- influence of conditions of crystallization (value of heat insulated coating) and chemical composition (extent of eutectic) at hardness level:

$$HSD = 73{,}83 - 2{,}5 \cdot h_c \qquad (2)$$

- influence of conditions of crystallization (value of heat insulated coating) and chemical composition (extent of eutectic) at coercive force level:

$$Hc = 19{,}46 - 2{,}71 \cdot h_c \qquad (3)$$

Equation (2) shows, that only speed of crystallization influences hardness level on working surface. It suppresses effects of chemical composition. Coefficient within this factor is not significant. Value of level of heat insulated coating has negative effect: hardness level decreases under increase of the layer. This decrease is 2.5 HSD when reaching this top level factor (+1). Level of hardness raises on 2.5 HSD, if value of heat insulated coating level take minimum significance. Factor is at lower level (-1).

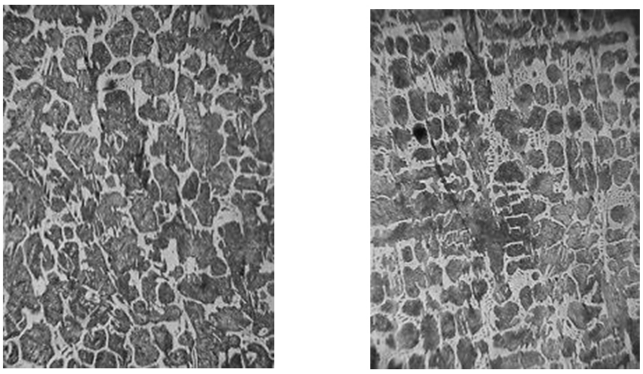
Pair-wise interaction of value of heat insulated coating level and extent of eutectic is not significant. That is effect of heat insulated coating does not depend on chemical composition at chosen interval of change. Middle significance of hardness for rolls within researched interval of factors was 73.83 HSD.

Also the value of heat insulated coating layer affects the level of coercive force (3): stresses level decreases on 2.71 A/cm by maximum value (+1) and by minimum (-1) – raises on the same value. Influence of chemical composition and pair-wise interaction of researched factors also is not significant. Middle significance of coercive force was 19.46 A/cm.

All received equations are adequate and forecast results of experiment at chosen area of factors with required exaction.

Metallographic analysis of researched samples showed, that casting structure consists of single compact inclusions of graphite, 30-35 % cementite and ledeburite. Samples with various level of hardness had structural differences size of grain at 35% и ледебурита. Samples with various level of hardness had structural differences. Size of grain in the sample with lower level of hardness is larger than templet with greater hardness (fig. 1).

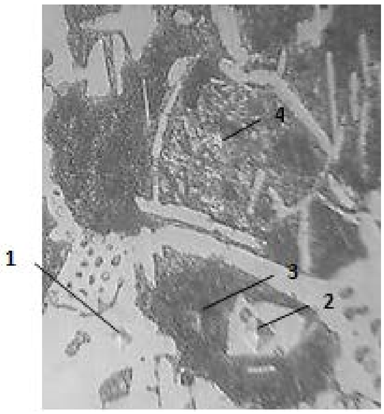
Martensite predominates in metallic matrix of harder sample, then in less hard – bainite. However measuring of microhardness of components of casting metallic base showed heterogeneity of its structure. It was established, that one grain may contain several components (table 2).



a) b)

Figure 1. Microstructure of researched samples of hardness (etching, × 100): a) - 70 HSD, b) – 76 HSD

Table 2. Phase identification in structure of researched sample with the help of microhardness tester PMT-3M

Microstructure of sample, etc., × 600 (reduced to 3 times)	Number measuring	Micro hardness, HV	Phase
	1	890	cementite
	2	792,82	carbide
	3	385,47	perlite
	4	461	martensite

Results of experiment showed that on the working layer surface the influence of heat insulated coating is significant on the level of hardness and coercive force. However metallography researches established that there is various combinations of components at structure of ingots, which are characterized by identical level of physical and mechanical properties. As a result performance criteria of rolls are changed.

Conclusion and perspective of further researches at given direction

1. The paper proposes to evaluate stress and deformed state of roll of large size at each stage of its production by operative measuring hardness on surface and magnetic diagnostic with portable coercimeter.

Experimental researches showed that level of coercive force increases at non-uniform distribution of hardness values along roll barrel. It was established that dispersion of hardness value along the working surface and increasing of coercive force are proportional:

$s^2_{HSD} = 0{,}5$ – $\Delta H_c = 2\ A/cm$; $s^2_{HSD} = 2{,}0$ – – $\Delta H_c = 4\ A/cm$; $s^2_{HSD} = 4{,}5 - \Delta H_c = 8\ A/cm$.

Such deviations at coercive force indications of optimal limits are depended on non-uniformity of structural changes during solidification of oversized roll from complex-alloyed melts at field of centrifugal forces.

2. Control of formation process of working layer structure and level of operating properties of massive rolls is realized by change of its chemical composition and speed of castings crystallization. Results of experimental researches showed that speed of crystallization determines formation of level of hardness and stresses on surface of working layer of analyzed rolls. It depends on value of heat insulated coating layer. Constructing mathematic models allowed to establish that effect of heat insulated coating does not depend on chemical composition at choosing distance factors changing. Its effect at level of hardness and stresses is insignificant as compared to influence of crystallization speed.

3. As a result of metallography structure analysis of samples of research rolls it was obtained, that castings with various level of hardness characterize insignificant difference at size of grain and phase in metal matrix of working layer. Inhomogeneous of composition of casting metal base in the same grain is revealed by method of micro hardness measuring.

It is necessary to carry out heat treatment of roll ingots and estimate their subsequent condition. Therefore, the work in this direction continues.

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