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THE DURABILITY IN EXPLOITION OF THE HOT ROLLING MILL CYLINDERS – IN LABORATORY EXPERIMENTS

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ABSTRACT
The research on rolling mills cylinders durability in exploitation experimentally defines an important chapter from the thermal fatigue of the organs of machines in the movement of rotation, in variable temperature mediums, and the mathematical molding establishes a methodology for the determination of the technological parameters values, for which a mechanical characteristic (the hardness) has the desirable values.
The technological manufacturing process of the rolling mills cylinders, as well as the quality of material used in manufacturing them, can have a different influence upon the quality and the safety in the exploitation. Our proposal approaches the issue of quality assurance of the rolling mills cylinders, from the viewpoint of the quality of materials, which feature can cause duration and safety in exploitation.
The experimented durability research, as well as the optimization of the manufacturing technology, allows the conclusion of direct results for the rolls. The beneficiaries of these results are the unit in which the rolls are manufactured, as well as the unit that exploits them.
The research on the durability in exploitation of hot rolling mill cylinders represents an important scientific and economical issue. The study represents a detailed approach of the influence of some technological factors on the durability in exploitation of rolling mill iron cylinders and suggests solutions meant to increase the durability of the rolls in exploitation.

KEYWORDS:
hot rolling, iron cylinders, durability in exploitation, thermal fatigue

1. INTRODUCTION

The technological manufacturing process of the rolling mills cylinders, as well as the quality of material used in manufacturing them, can have a different influence upon the quality and the safety in the exploitation. Our proposal approaches the issue of quality assurance of the rolling mills cylinders, from the viewpoint of the quality of materials, which feature can cause duration and safety in exploitation.

In these sense, our researches propose, on aside, to analyze the durability in industrial exploitation of rolling mills cylinders - analysis materialized from prism of the laboratory experiment, and on another side, the optimization of the manufacturing

technology of the cast rolls, especially those from cast-iron - using electronic calculus technique as the molding phenomenon and mathematical interpretation of the technological processes.

The research on rolling mills cylinders durability in exploitation experimentally defines an important chapter from the thermal fatigue of the organs of machines in the movement of rotation, in variable temperature mediums, and the mathematical molding establishes a methodology for the determination of the technological parameters values, for which a mechanical characteristic (the hardness) has the desirable values.

The experimented durability research, as well as the optimization of the manufacturing technology, allows the conclusion of direct results for the rolls. The beneficiaries of these results are the unit in which the rolls are manufactured, as well as the unit that exploits them.

These researches are trying to give answers to most actual problems related to the increase of hardness of rolling mill cylinders. They are characterized by a complex system of cracking of the superficial caliber layer or they simply break because of the thermal shocks caused by the contact of the hot metal with the water-cooled cylinders.

The study represents a detailed approach of the influence of various technological factors on the durability in exploitation of rolling mill cylinders made of nodular irons with different chemical composition and suggests solutions meant to increase the endurance of rolling mill cylinders in exploitation. The purpose of this work is to present few directions concerning the quality improvement of rolling iron cylinders, aiming the increasing of durability and safety in operation.

2. THE RESEARCHES OF DURABILITY IN THE EXPLOITATION

The researches of durability in the exploitation of cast from cast-iron rolls, constitute a scientifically novelty, and experimentally define an important chapter from the thermal fatigue of the organs of machines in the movement of rotation, in variable temperature mediums. Hot rolling mills cylinders work the in the variable compound solicitations, due to lamination process and which repeat to regular intervals of time.

All these phenomena, which are more or less emphases depending on the type and typical of rolling mills, are not taking into consideration in the classic calculus of rolls. If the study of the rolls resistance is extended upon their durability, we must consider the whole complex of tensions with mechanic and thermal influences. The research on durability in exploitation of hot rolling mills cylinders assures relevant conditions for the appropriation of the research methods of the thermal regimes that are submitted the rolls or other organs of machines, that works in constant (symmetrical) or variables (asymmetrical) thermal solicitation conditions.

The recommendations for the increase of the duration of exploitation and remove of the damages through the accidental rupture of rolls from the stands of lamination, the attenuation of rolls thermal fatigue, the avoiding of thermal shock and their rational exploitation are actuality issues, that must be continuously researched. In this trend is situated the research of the thermal fatigue phenomena, materialized in technical reports, whose beneficiary is the unit in which the rolls are exploited, as well as through scientific papers, that can develop the framework of scientific research. These researches results lead to direct conclusions about the cast-iron rolls, and permit their comparison with date about steel rolls, area studied thoroughly researched of specialists.

The work is of practical immediate utility, inscribing itself in the context of technical capitalization of the manufacturing technologies and of exploitation of cast-iron rolling mill cylinders, for which exists an attentive preoccupation both from foundry sectors, as well as from lamination sectors, having as determinate aim the quality assurance and increase the durability in exploitation.

The quality of rolls is determined through hardness and through wear resistance, last indexes having a special importance for all modern rolling mills with a growth production. Of major importance for the rolls exploitation is not merely growth resistance, but also the ability to oppose to different types of wear. Thus, rolling mill cylinders considerable

influence the specific production and the qualitative level of laminates, reason for which they are given a special attention, in manufacturing, as well as in usage. These requirements can't be completely fulfilled, compelling to the granting of priorities depending on the type of laminates, therefore to compromises. At large, the problem is reduced to the correct material choice, eased by the rich available experience in the current conditions of manufactured and burdened, in the same time, by the large diversity of material used.

Although the manufacture of rolls is in continuously perfecting, the requirements for superior quality rolls are not yet completely satisfied, in many cases, the absence of quality rolls preventing the realization of quality laminates or the realization of productivities of which rolling mills are capable.

3. THE EXPERIMENTAL EQUIPMENTS

The research uses data collected from the industrial use at the Iron And Steel Integrated Plant of Hunedoara, as well as laboratory experiments carried out on a unique, complex and original installation.

The experiments are made on groups of six rings, with a 250 mm exterior diameter, carried out from the studied types of industrial rolls. Having in view the research, three armatures of specimens were made, each with six rings and every ring made of nodular graphite iron used in the making of rolls in heavy section mills.

These rings were subject to different cyclical thermal solicitations, which, during the period of a rotation of the main axis, on one hand warm up in an electric furnace at different temperatures, and on the other hand cool in different environments, respectively in air, water and carbonic snow jets.

During the experiments, after a certain number of stress cycles, the surface of the sharp sides of the rings presents signs of cracks because of the thermal fatigue. After establishing the number of stress cycles, until the first thermal fatigue caused cracks appear, durability histograms are done to each type of material, used to manufacture rolling mill cylinders and to each type of stress.

Table 1. The experimental regimes

The name of the characteristic elements from the experimental regime	M.U.	Experimental regimes		
		A	B	C
Rotation number of the tryouts mounted on the main axle	[rot / min]	30.6	30.6	30.6
The temperature of the electric furnace medium	[°C]	910±10°C	910±10°C	910±10°C
The tryouts warming time	[s]	0.98	0.98	0.98
The tryouts cooling time	[s]	0.98	0.98	0.98
The heat introduction angle	[rad]	π	π	π
The cooling evacuation	[rad]	π	π	π
The cooling medium	-	air	circulated water	carbonic snow

Based on the previous data presented, we chose three experimental thermal regimes, having the main elements presented in Table 1. The order of the experiments was regime A, B and C. During the experiments, was registered permanently the temperature of the electric furnace medium in stationary regime (910°C) and the temperature variations to one revolution of the rings, on the exterior surface as well in the superficial layer at Δr = 1.5 and 3 mm depth.

During the experimental process of durability at thermal fatigue was utilized the electronic calculus technique using a program working on one IBM PC computer, for ADAM–4018 modules at the entrance and ADAM–4520 converter to the exit. In this way has been registered the cyclic temperature variations in points, at the surface and in the superficial layer.

4. RESULTS AND ANALYSES

Analyzing the temperature variations diagrams, considered as isochronal estates, during the thermal fatigue experimental estates of the tryouts in A, B and C regime, we

can observe that the highest temperature of the rings is registered on the exterior surface (for Δr = 0mm), in the A regime when the cooling has been effected in open air. In the B regime, having a recycling water bath cooling system, the temperature variations curves have a less accentuated downgrade in the area of the cooling angle, reaching the maximal temperature on the rings surface (Δr = 0mm), and the minimal temperature for Δr = 3mm. In the C loading regime was used carbon-dioxide ice blasted in by a distributive collector, the temperature variations curves becoming, in cooling area, even more accentuated, the maximal temperature on the rings surface is registered for the surface, and the minimal temperature for Δr = 3mm, in the superficial layer.

As a general observation, for all the three registered diagrams, the temperature variations curves peaks have a certain displacement on the abscissa, fact that indicates that the heat transmitting time in the rings mass, respectively in the superficial layer. The situation is similar in a reverse way to the cooling process too, being more accentuated in the B and C regimes, when the rings surface cools faster and the superficial layer at the Δr = 1.5 mm depth remains warm up by higher temperatures that the surface ones.

Table 1. The number of thermal cycles and cyclical thermal solicitation regimes

No. crt.	Type	Number of thermal cycles		
		The cyclical thermal solicitation regimes		
		A	B	C
1.	FNS1	$201 \cdot 10^3$	$183 \cdot 10^3$	$169 \cdot 10^3$
2.	FNS1	$224 \cdot 10^3$	$194 \cdot 10^3$	$176 \cdot 10^3$
3.	FNS2	$175 \cdot 10^3$	$160 \cdot 10^3$	$152 \cdot 10^3$
4.	FNS2	$194 \cdot 10^3$	$178 \cdot 10^3$	$165 \cdot 10^3$
5.	FNS2	$191 \cdot 10^3$	$179 \cdot 10^3$	$161 \cdot 10^3$
6.	FNS2	$182 \cdot 10^3$	$171 \cdot 10^3$	$157 \cdot 10^3$
7.	55VMoCr12	$194 \cdot 10^3$	$181 \cdot 10^3$	$159 \cdot 10^3$
8.	90VMoCr15	$175 \cdot 10^3$	$162 \cdot 10^3$	$148 \cdot 10^3$
9.	OTA3	$245 \cdot 10^3$	$225 \cdot 10^3$	$195 \cdot 10^3$
10.	65VMoCr15	$186 \cdot 10^3$	$169 \cdot 10^3$	$152 \cdot 10^3$
11.	FNS2	$218 \cdot 10^3$	$182 \cdot 10^3$	$173 \cdot 10^3$
12.	FD2	$178 \cdot 10^3$	$165 \cdot 10^3$	$154 \cdot 10^3$

Table 2. The chemical composition and the hardness of the materials included in study

TYPE	No.	Chemical composition, [%]								Hardness, [HB]	
		C	Si	Mn	S	P	Ni	Cr	Mo	body	necks
FNS1	1. 2. 3.	3.41	2.19	0.72	0.015	0.148	2.08	0.72	0.23	338	264
FNS1	1. 2. 3.	3.40	1.94	0.67	0.015	0.148	2.11	0.68	0.27	342	270
FNS2	1. 2. 3.	3.34	1.79	0.58	0.017	0.106	1.12	0.30	0.71	457	390
FNS2	1. 2. 3.	3.20	1.91	0.54	0.011	0.117	1.44	0.41	0.31	393	365
FNS2	1. 2. 3.	3.21	1.67	0.54	0.018	0.116	1.46	0.65	0.24	406	330
FNS2	1. 2. 3.	3.16	1.79	0.61	0.024	0.121	0.81	0.39	0.21	367	310
55VMoCr12	1. 2. 3.	0.56	0.22	0.37	0.021	0.029	0.22	1.20	1.20	280	218
90VMoCr15	1. 2. 3.	0.90	0.24	0.35	0.023	0.025	0.18	1.49	0.21	315	245
OTA3	1. 2. 3.	1.98	0.72	0.84	0.015	0.034	1.62	1.14	0.36	390	320
65VMoCr15	1. 2. 3.	0.65	0.34	0.72	0.020	0.021	0.21	1.56	0.45	310	280
FNS2	1. 2. 3.	3.34	1.97	0.76	0.022	0.160	1.94	0.64	0.24	420	327
FD2	1. 2. 3.	2.93	0.56	0.64	0.038	0.39	0.42	0.62	0.27	514	293

During the durability experiments, after the A, B and C regime, applied separately for each set of tryouts formed of six rings, representing the 6 studied cast irons (with different chemical compositions), aiming by visualization the appearance of the first thermal fatigue cracks. These values are compared with the results from another series of experiments.

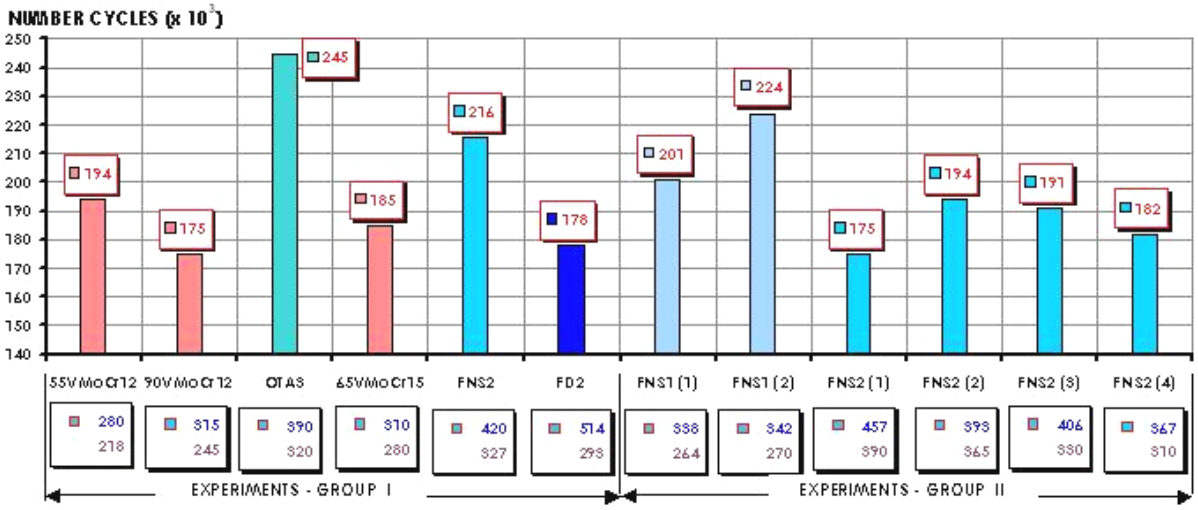

Fig.1. Durability histograms (for the regime A)

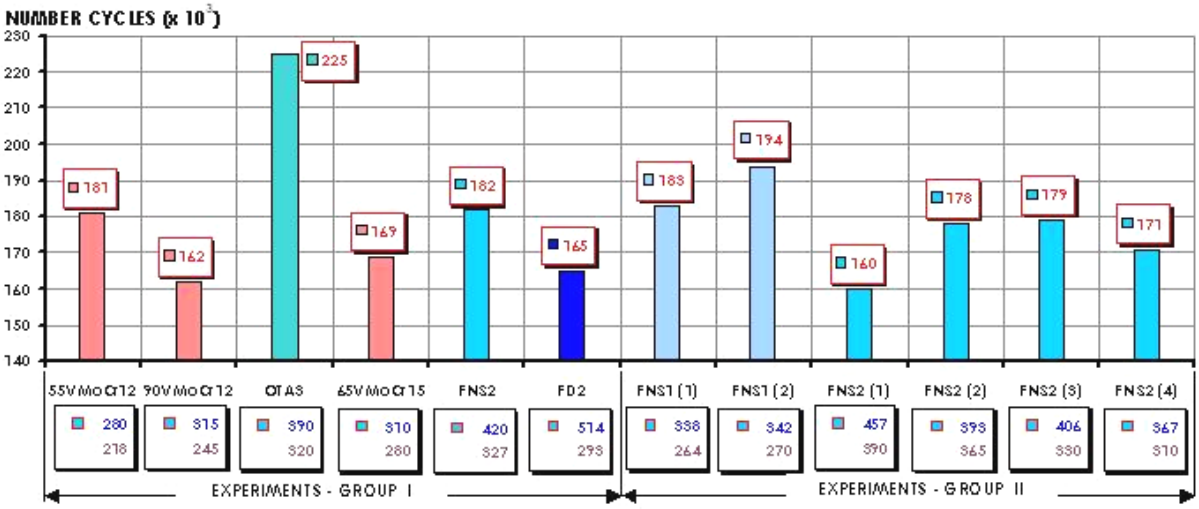

Fig. 2. Durability histograms (for the regime B)

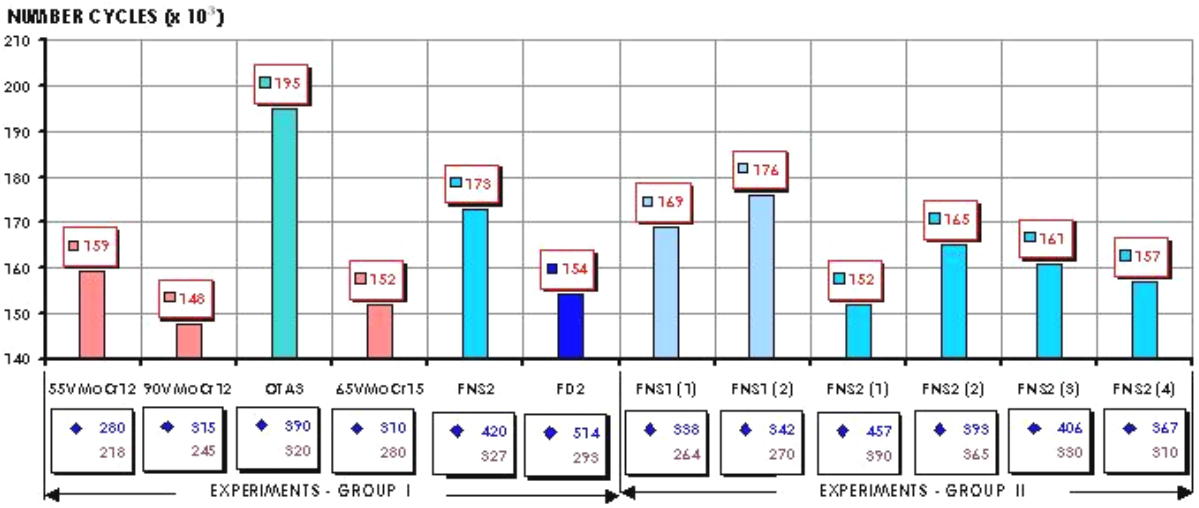

Fig. 3. Durability histograms (for the regime C)

After the experimental exploiting durability tests, evaluated in thermal loading cycles, were made durability histograms, for each loading regime and for each mark of studied material, the results being presented in Fig. 1, Fig. 2 and Fig. 3. (Table 1) The chemical composition and the hardness of the materials included in study, in both series of experiments, in the Table 2 are presented.

5. CONCLUSIONS

This research is a novelty scientifically for the fundamental and experimental research area upon the hot rolling cylinders. The research has contains concrete elements of practical immediate utility in the metallurgical enterprises, for the improvement quality of cylinders, having final as aim growth durability and safety in exploitation.

The research on the durability in exploitation of the hot rolling mill cylinders is to be extended further on different brands of steels and irons used for the manufacturing of hot rolling mill cylinders, depending on the durability up to the point of fissures and thermal fatigue cracks. Therefore, it is recommended to use the most rational and economical materials, as well as new, more performing materials to manufacture hot rolling mill cylinders.

In this sense, a few conclusions regarding the results are presented:

- in stress regime A, the materials under study resisted longest at stress cycles, until the first thermal fatigue cracks appeared (loading regime); in stress regime B, the first thermal fatigue cracks appeared in a smaller number of stress cycles (medium regime); in regime C, the thermal fatigue cracks appeared at the lowest number of stress cycles (heavy regime).
- uses one regimes of heating-cooling solicitation on the different regimes, subdued the analysis samples shackles from rolling mill, after the realization of the hot-roll campaigns in the roughing stands sectors, having different chemical compositions. Each of the materials from which the ring are manufactured (cast irons, with nodular or lamellar graphite, steels and hypoeutectic steel), behaved differently to the thermal fatigue solicitations, although technological they do the part from one the group of classify of rolling mill cylinders, that is the semi-hard, type FNS. Consequently, the chemical composition can assure both the hardness of rolling mill cylinders, and durability in thermal fatigue conditions.
- analyzing the results, the cast irons of the rings (2) and (1), that is one with the class of hardness 1, had best behavior to the thermal fatigue, these supporting 224000 the cycles in the regime respectively 201000 cycles for same regimes of solicitation.
- the type of stress which gave the best results regarding stability to the fatigue is OTA3 steel type and in the case of the two types of iron used in experimental research, a better behaviour was noticed at FNS2.
- the most dissatisfactory behavior was fallen across cast-iron of the ring (3), from class (2) of hardness.
- the irons of the rings (4) and (5) behaved both in satisfactory ways.
- the laboratory experiments demonstrated that an optimal determined chemical composition could assure both the wear resistance (through the hardness), and a proper behavior in the thermal fatigue solicitations.

The durability in exploitation of the rolling mill cylinders is little approached in the reference literature, both in Romania and worldwide. Up to this moment, there is no reference publication to minutely deal with the theoretical and experimental aspects of this theme of research. For this reason, this research is a novelty scientifically for the fundamental and experimental research area upon the hot rolling cylinders. The research has contains concrete elements of practical immediate utility in the metallurgical enterprises, for the improvement quality of cylinders.

The research uses data collected from the industrial use, as well as laboratory experiments carried out on a unique, complex and original installation. These laboratory experiments are trying to give answers to most actual problems related to the increase of

hardness of rolling mill cylinders. They are characterized by a complex system of cracking of the superficial caliber layer or they simply break because of the thermal shocks caused by the contact of the hot metal with the water-cooled cylinders. The laboratory experiments demonstrated that an optimal determined chemical composition could assure both the wear resistance (through the hardness), and a proper behavior in the thermal fatigue solicitations.

The quality of rolls is determined through hardness and through wear resistance, last indexes having a special importance for all modern rolling mills with a growth production. Of major importance for the rolls exploitation is not merely growth resistance, but also the ability to oppose to different types of wear. Thus, rolling mill cylinders considerable influence the specific production and the qualitative level of laminates, reason for which they are given a special attention, in manufacturing, as well as in usage. These requirements cannot be completely fulfilled, compelling to the granting of priorities depending on the type of laminates, therefore to compromises. At large, the problem is reduced to the correct material choice, eased by the rich available experience in the current conditions of manufactured and burdened, in the same time, by the large diversity of material used.

Although the manufacture of rolls is in continuously perfecting, the requirements for superior quality rolls are not yet completely satisfied, in many cases, the absence of quality rolls preventing the realization of quality laminates or the realization of productivities of which rolling mills are capable.

To the selection of materials is considered the type of rolling mill, the sizes of rolls (in specially this diameter), the speeds of lamination, the stands from the train of lamination for which is achieved rolls, the working temperature in the lamination process, the module of cooling during work, the size caliber, the pressure on rolls, the rolled material hardness, etc.

The choice of material for rolls is the operation which takes into consideration the own solicitations of the lamination process afferent to the type of laminates (semi product or the finite laminate), and the features of different materials considerate optimum in the fabrication of different typo-dimensions of rolls.

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