ABOUT THE DURABILITY IN EXPLOITATION OF THE CAST IRON HOT ROLLING MILL ROLLS IN FEW EXPERIMENTAL RESULTS

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Abstract
The technological manufacturing process of the rolling mills rolls, 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 rolls, from the viewpoint of the quality of materials, which feature can cause duration and safety in exploitation. 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 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 research on the durability in exploitation of hot rolling mill rolls 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 rolls and suggests solutions meant to increase the durability of the rolls in exploitation. 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 rolls, 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.

Keywords: rolling rolls, thermal cycles, thermal regimes, durability, experiments

1 Introduction

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 rolls work the in the variable compound solicitations, due to lamination process and which repeat to regular intervals of time. [1-3,10-11,15-16]

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. [1-6,17-21] 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 rolls 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 research on rolling mills rolls 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. [1-3,10-11,15-16,19-21] The experimented durability research, as well as the optimization of the manufacturing technology, allows the conclusion of direct results for the rolls. [1-3,10-21] The beneficiaries of these results are the unit in which the rolls are manufactured, as well as the unit that exploits them. [1-3]
These researches are trying to give answers to most actual problems related to the increase of hardness of rolling mill rolls. [1-9,12-14,21] 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 rolls. [1-6]

2 Laboratory research

The research uses data collected from the industrial use, as well as laboratory experiments carried out on a unique, complex and original installation. [1-3,10-20] These laboratory experiments are trying to give answers to most actual problems related to the increase of hardness of rolling mill rolls. 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 rolls. 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. [1-3,12-17,21]
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. [1-9] 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 rolls 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. [1-6,10-11,17-18] 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. [1-3,12-14,21]
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. [1-4] 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.[1-3,10-21]
The durability in exploitation of the rolling mill rolls is little approached in the reference literature, both in Romania and worldwide.[5-9] 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 rolls.[1-3] The research has contains concrete elements of practical immediate utility in the metallurgical enterprises, for the improvement quality of rolls, having final as aim growth durability and safety in exploitation. The research on the durability in exploitation of the hot rolling mill rolls is to be extended further on different brands of steels and irons used for the manufacturing of hot rolling mill rolls, depending on the durability up to the point of fissures and thermal fatigue cracks.

3 Materials and Experimental Methods

The research uses data collected from the industrial use at the Iron and Steel Integrated Plant of Faculty of Engineering from Hunedoara, as well as laboratory experiments carried out on a unique, complex and original installation. [1-3,10-16,21]
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 rolls and to each type of stress. [1-3,10-16,21]
Based on the previous data presented, we chose three experimental thermal regimes, having the main elements presented in **Table 1**.

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 electric furnace medium’s temperature	[°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

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. [1-3,10-11,15-16]

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. [1-3,10-11]

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	$178 \cdot 10^3$	$165 \cdot 10^3$	$154 \cdot 10^3$

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.

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**. (according with **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.

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

Type	Chemical Composition, [%]								Hardness, [HB]	
	C	Si	Mn	S	P	Ni	Cr	Mo	body	necks
FNS1	3.41	2.19	0.72	0.015	0.148	2.08	0.72	0.23	338	264
FNS1	3.40	1.94	0.67	0.015	0.148	2.11	0.68	0.27	342	270
FNS2	3.34	1.79	0.58	0.017	0.106	1.12	0.30	0.71	457	390
FNS2	3.20	1.91	0.54	0.011	0.117	1.44	0.41	0.31	393	365
FNS2	3.21	1.67	0.54	0.018	0.116	1.46	0.65	0.24	406	330
FNS2	3.16	1.79	0.61	0.024	0.121	0.81	0.39	0.21	367	310
55VM	0.56	0.22	0.37	0.021	0.029	0.22	1.20	1.20	280	218
90VM	0.90	0.24	0.35	0.023	0.025	0.18	1.49	0.21	315	245
OTA3	1.98	0.72	0.84	0.015	0.034	1.62	1.14	0.36	390	320
65VM	0.65	0.34	0.72	0.020	0.021	0.21	1.56	0.45	310	280
FNS2	3.34	1.97	0.76	0.022	0.160	1.94	0.64	0.24	420	327
FD2	2.93	0.56	0.64	0.038	0.39	0.42	0.62	0.27	514	293

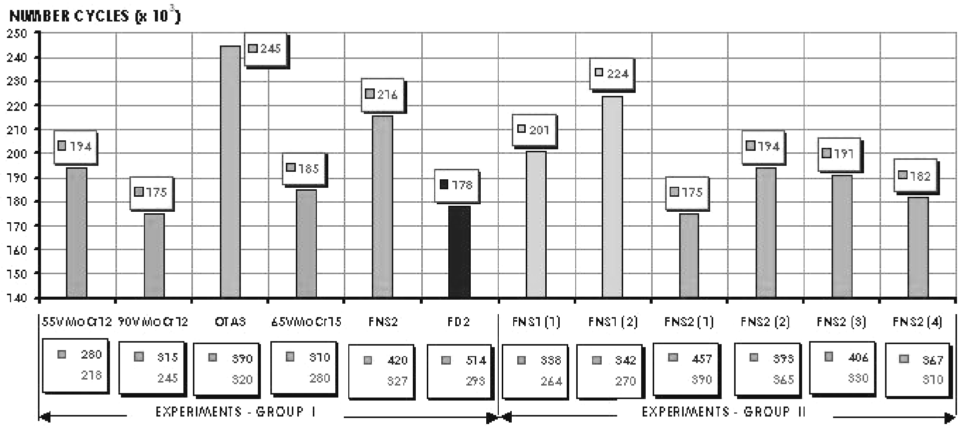

Fig.1 Durability histograms (for the regime A)

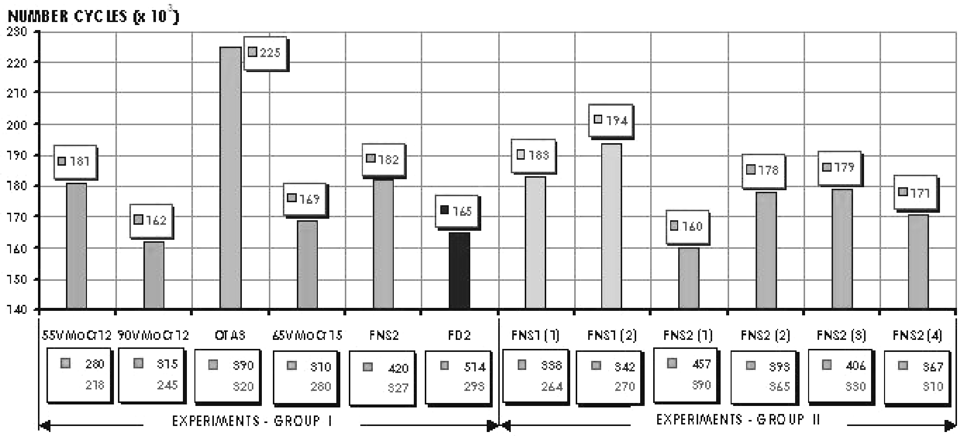

Fig.2 Durability histograms (for the regime B)

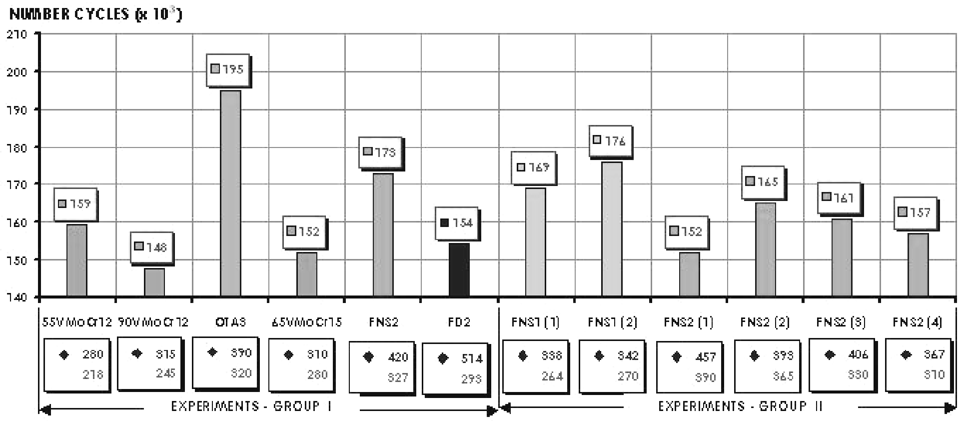

Fig.3 Durability histograms (for the regime C)

5 Conclusions

The rolling rolls durability is an important factor for determining the metal consumption of one rolling mill because a low durability increases the time for changing the calibers of the rolling-mills, the labor for recalibration and the quantity of waste bars in order to regulate the line after any change, and it also influences the productivity and the saving of the rolling-mill. In such conditions, economically speaking, it is not rational to use the cheapest rolls because they do not ensure the lowest consumption in case of high productivity of a rolling-mill.

Therefore, it is recommended to use the most rational and economical materials, as well as new, more performing materials to manufacture hot rolling mill rolls. In this sense, a few conclusions regarding the results are presented:

- 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 rolls, that is the semi-hard, type FNS. Consequently, the chemical composition can assure both the hardness of rolling mill rolls, and durability in thermal fatigue conditions.
- 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).
- analyzing the results, the cast irons of the rings (no. 2) and (no. 1), that is one with the class of hardness 1, had best behavior to the thermal fatigue, these supporting 224000 ($224 \cdot 10^3$) the cycles in the regime respectively 201000 ($201 \cdot 10^3$) 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 behavior was noticed at FNS2.
- the most dissatisfactory behavior was fallen across cast-iron of the ring (no. 3), from class 2 of hardness.

- the irons of the rings (no. 4) and (no. 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.

Therefore, the installation that we have designed, made, and described in our work ensures any possibility of study of the durability through cyclic thermal charge, on some ring samples made of the same material as the industrial rolling rolls. This installation allows us to make some research about the durability and of the mechanisms subject to thermal fatigue (the charge equipments arms, saw disks, scissors blades for warm cutting, guiding rolls for the continuous molding installation etc.).
This experimental installation allows the specialists to appreciate the durability of the rolling rolls according to the number of stress cycles of thermal fatigue, until the first cracks on the surface of the calibers occur. The equipment allows us to determine the durability in laboratory experiments and to compare any result obtained for the working durability of the industrial rolling rolls.

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