RESEARCH ON THE DURABILITY IN EXPLOITION OF THE HOT ROLLING MILL CYLINDERS

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ABSTRACT
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.
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. The research uses data collected from the industrial use, as well as laboratory experiments carried out on a unique, complex and original installation.

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

1. INTRODUCTION

Having in view the statistical data calculated for 10 years, the total consumption of rolling mill cylinders represents 0.785…0.8 kg/tone of rolled steel. Nationwide, the 5 million tones steel being rolled every year represents a consumption of 4,000 tones cylinders, worth of 6 million euro/year, which imposes large research with an important economic and scientific impact. It is noticeable that approximately 1/8...1/10 of the rolls are removed from exploitation because of the thermal shock caused breakings, which cause accidental damage and stoppage, and the losses expand over the rolls cost, as well as production losses, disturbing the entire technological flux.

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 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.

Fig. 1 presents the construction plan of the installation for determining the durability of the hot rolling mill cylinders. This installation provides the possibility of further studies and also to establish the durability in exploitation for all types of rolls used presently in industrial mills.

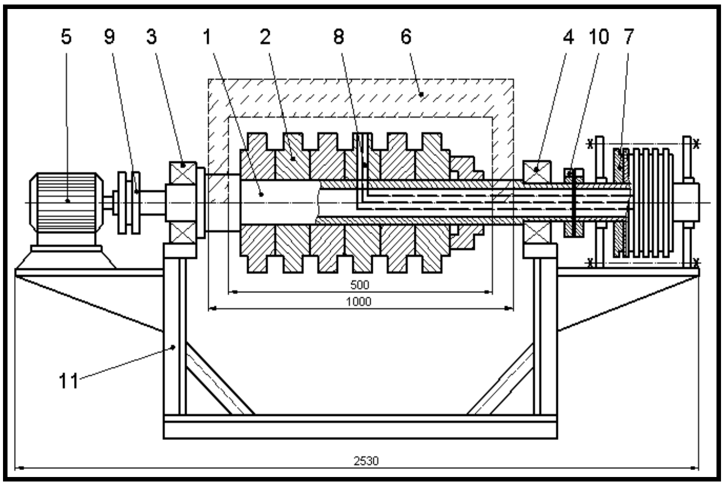

Figure 1. The construction plan of the installation for determining the durability of the hot rolling mill cylinders
1. main axis; 2. experimental samples; 3,4. bearings;
5. asynchrony electric engine; 6. electric resistance furnace;
7. thermo tension collector; 8. pin;
9, 10. couplings; 11. metallic skeleton

The experiments are made on groups of six rings, with a 250 mm exterior diameter, carried out from the studied types of industrial rolls (Fig. 2). 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. They appear at different intervals during the stress, intervals according to which the number of cycles is to be established. These cycles differ, depending on the type of materials studied. During the experiments the temperature variation is recorded in the ring shaped specimens (samples), as wells as the temperature of the electric furnace with automatic adjustment and maintenance at previously established values.

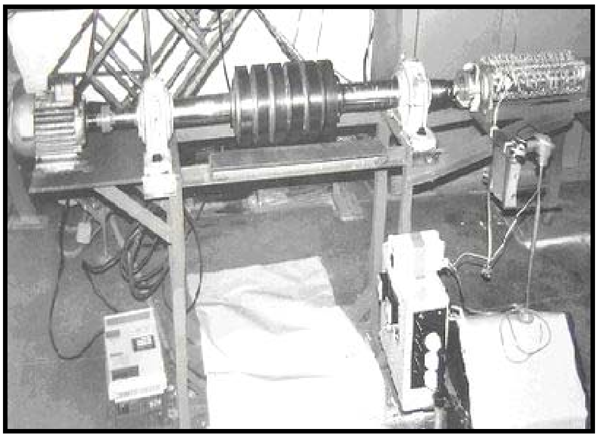

Figure 2. Assembly of main axis and ring shaped samples, under durability tests

Figure 3. Assembly of conical pin fitted Pt-Pt/Rh thermocouplings

To perform the measurements of temperature variation in the experimental rings, one of them is implanted with a conical pin with initially equipped Pt-Pt/Rh thermocouples. The wire diameter is 0.06 mm and the inertion response under a tenth of a second. These thermocouples measure temperature variation on the surface of the sample and the Δr = 0; 1.5 and 3.0 mm depths. They are presented together with the interior assemblage, in Fig. 3. The pin with the assembled thermocouples to be fit in the ring is presented in Fig. 4.

Figure 4. Thermo-coupled pin assembled and prepared for installation in the ring sample

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.

3. WORKING REGIMES

From the study of the thermal regime of the hot rolling cylinders, we chose the minimal value for the rotation number of the tryouts constrained to durability test being as 30.6 rot/min, producing the highest thermal fatigue because the thermal tensions appearing as effect of temperature variations are maximal and, after a relative small number of rotations, appear the first thermal fatigue cracks.

Regarding the temperature of the electric furnace medium intended for experimental rings warming, this has to be as high as possible in order that the tryouts reach a stabilized regime to a maximal possible temperature. In our case, the temperature of the two resistors electric furnace medium, having four curled spirals each, was calculated to 1000°C and we obtained 960°±10°C, but the experiments were effectuated at 910°±10°C.

In order to increase the number of the loading cycles, until the first thermal fatigue cracks appear, we have tried to maintain as high as possible temperature for tryouts, and the cooling fast and accentuated. Each of the three sets of tryouts consisting in six rings were constrained to a working regime, pursuing the calculated moment of the appearance of the thermal fatigue first cracks, registering the number of loading cycles.

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

Table 2.Cyclical temperature variation on the surface and in the superficial layer of samples, exploited in regime A, with n = 30.6 rot/min, at a furnace temperature (910± 10^{0}C)

No.	The temperatures variations, [°C]			No.	The temperatures variations, [°C]		
	Δr = 0mm	Δr = 1.5mm	Δr = 3mm		Δr = 0mm	Δr = 1.5mm	Δr = 3mm
0	242.2	231.2	219.6	21	758.2	613.4	488.6
1	318.4	273.1	241.9	22	762.2	620.2	492.2
2	374.2	319.2	256.8	23	749.1	607.4	491.2
3	424.0	355.2	285.3	24	722.3	601.4	480.1
4	462.3	357.6	301.2	25	712.6	589.7	479.7
5	498.2	392.6	319.3	26	682.3	546.7	459.4
6	518.5	412.3	339.4	27	542.5	478.6	420.2
7	573.4	442.2	361.9	28	516.4	458.0	403.0
8	599.4	458.7	373.1	29	479.5	432.7	384.0
9	628.2	477.8	389.5	30	453.0	422.9	379.2
10	649.3	498.7	396.4	31	449.9	407.2	352.1
11	669.2	511.1	413.4	32	436.3	387.1	341.1
12	682.1	527.7	428.6	33	421.7	347.2	327.9
13	706.4	549.4	441.2	34	401.4	329.9	312.8
14	729.6	552.4	449.2	35	386.4	322.3	302.7
15	746.1	572.1	452.6	36	346.6	298.8	282.6
16	758.2	576.2	455.2	37	322.4	267.2	241.7
17	762.9	586.2	462.3	38	302.1	256.2	239.9
18	766.3	592.5	463.7	39	287.1	246.3	231.2
19	772.2	602.4	469.5	40	239.9	231.2	219.2

20	776.7	608.9	472.3	41	242.2	231.2	219.6

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, the obtained results from the file being showed in *Table 2*, *3* and *4* and the diagrams in Fig. 5, 6 and 7.

Table 3.Cyclical temperature variation on the surface and in the superficial layer of samples, exploited in regime B, with n = 30.6 rot/min, at a furnace temperature (910± 10^{0}C)

No.	The temperatures variations, [°C]			No.	The temperatures variations, [°C]		
	Δr = 0mm	Δr = 1.5mm	Δr = 3mm		Δr = 0mm	Δr = 1.5mm	Δr = 3mm
0	215.0	191.0	150.0	21	745.0	530.4	347.1
1	275.1	251.0	180.4	22	701.1	515.1	343.0
2	289.1	278.0	195.3	23	621.2	492.0	331.1
3	322.4	302.0	210.8	24	571.0	476.2	323.2
4	377.0	333.0	229.3	25	541.9	450.2	318.1
5	396.3	355.6	240.0	26	521.2	427.5	309.9
6	412.4	379.4	253.4	27	488.8	402.3	295.4
7	467.3	403.8	266.5	28	420.2	380.4	278.6
8	491.4	425.9	277.6	29	356.5	346.0	262.8
9	532.2	444.0	284.4	30	341.2	323.0	251.6
10	579.5	460.5	293.3	31	312.4	303.8	235.2
11	611.9	475.0	300.2	32	292.7	295.2	223.4
12	630.0	488.2	309.5	33	287.0	280.4	207.8
13	669.7	499.6	313.6	34	249.3	262.8	195.4
14	682.0	509.7	329.6	35	216.0	248.9	190.0
15	710.0	523.0	336.2	36	208.6	236.0	170.0
16	725.0	528.0	340.9	37	197.0	218.6	166.0
17	733.0	540.0	343.2	38	195.2	209.7	162.2
18	755.5	550.0	340.1	39	204.1	197.0	155.0
19	759.7	555.0	345.9	40	207.3	189.0	152.1
20	767.4	545.0	348.3	41	221.2	191.0	150.0

Table 4.Cyclical temperature variation on the surface and in the superficial layer of samples, exploited in regime C, with n = 30.6 rot/min, at a furnace temperature (910± 10^{0}C)

No.	The temperatures variations, [°C]			No.	The temperatures variations, [°C]		
	Δr = 0mm	Δr = 1.5mm	Δr = 3mm		Δr = 0mm	Δr = 1.5mm	Δr = 3mm
0	222.1	180.3	140.6	21	750.0	505.0	298.3
1	270.6	200.1	152.3	22	737.0	492.4	292.6
2	351.0	232.4	173.5	23	654.4	474.6	286.0
3	414.3	259.7	190.2	24	542.7	450.0	275.2
4	457.7	287.6	207.5	25	472.9	429.0	270.5
5	509.6	314.0	220.2	26	428.7	405.6	265.4
6	524.0	332.3	229.4	27	382.8	375.1	256.3
7	561.2	358.3	241.6	28	321.0	350.2	243.1
8	585.8	375.1	250.2	29	284.0	310.9	234.0
9	612.5	393.4	260.1	30	250.6	291.0	220.5
10	631.9	413.1	269.3	31	233.4	270.0	205.6
11	653.7	430.0	275.9	32	223.2	255.0	196.5
12	669.4	445.3	280.1	33	212.9	248.4	186.3
13	689.3	455.2	285.6	34	205.7	233.0	180.1
14	705.5	469.7	290.0	35	202.1	222.0	175.6
15	717.7	480.2	293.1	36	198.5	212.2	168.0
16	733.1	485.4	294.2	37	193.4	202.0	163.0
17	743.6	494.5	298.1	38	195.7	195.1	152.6
18	747.1	499.3	140.6	39	199.8	186.9	150.1
19	749.6	501.1	152.3	40	204.0	183.0	142.0

20	757.2	503.4	173.5	41	212.6	181.2	141.3

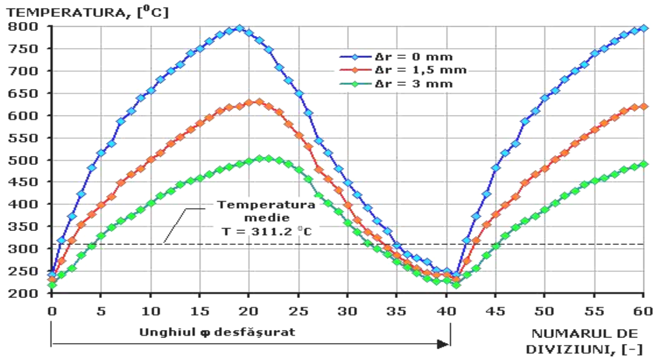

Fig. 5. The cyclic temperature variations in points, at the surface and in the superficial layer (A)

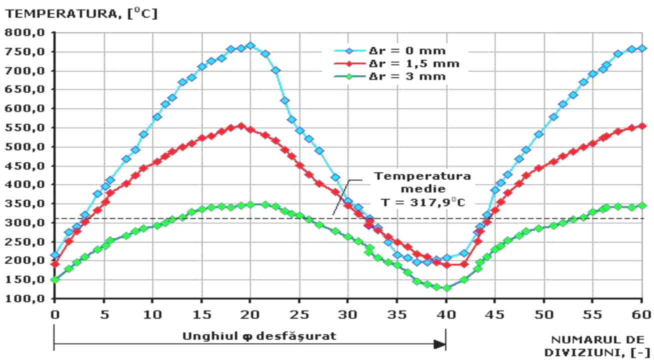

Fig. 6. The cyclic temperature variations in points, at the surface and in the superficial layer (B)

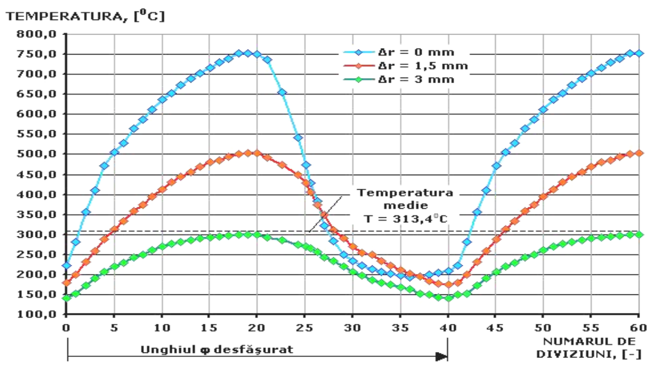

Fig. 7. The cyclic temperature variations in points, at the surface and in the superficial layer (C)

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 registered temperature on the exterior surface of the rings was 776.7°C (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 767.4°C (for Δr = 0mm), and the minimal temperature was 152°C (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 being 757.2°C (for Δr = 0 mm), and the minimal temperature in the superficial layer 140.6°C(for Δr = 3mm).

The synthesis of the characteristic data for the registered temperature variations in the experimental loading regime A, B and C are presented in the Table 5.

Table 5. Synthesis of the characteristic data for cyclical variation of temperature, from the superficial layer of ring typed tryout experimentally exploited in A, B, C regime

Diagram of the cyclical variation of the temperatures, according to experimental exploitation regime	Depth of the superficial layer Δr [mm]	Limit temperature variation resulting from experiments [^{0}C]	
		Maximal	Minimal
Experimental stress „A" Regime (see fig. 5)	0	776.7	239.2
	1.5	620.2	231.2
	3.0	499.2	219.2
Experimental stress „B" Regime (see fig. 6)	0	767.4	195.2
	1.5	505.0	180.3
	3.0	348.3	152.1
Experimental stress „C" Regime (see fig. 7)	0	757.2	204.0
	1.5	505.0	180.3
	3.0	292.6	140.6

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.

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 first thermal fatigue cracks appear on the sharp lateral exterior edges at a Φ250 mm maximal diameter, on each ring assembled in the packing, after a certain determined number of thermal loading cycles. The visualizations made in order to observe the thermal fatigue cracks were made twice per day, calculating the number of cycles passed after the each visualization.

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. 8, Fig. 9 and Fig. 10. (*Table 6*).

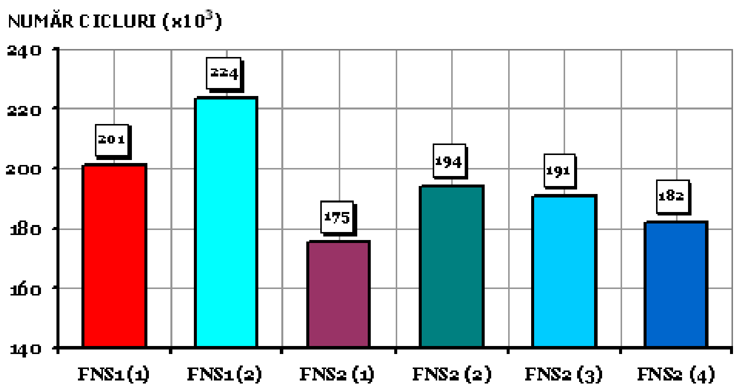

Fig.8. Durability histograms (for the regime A)

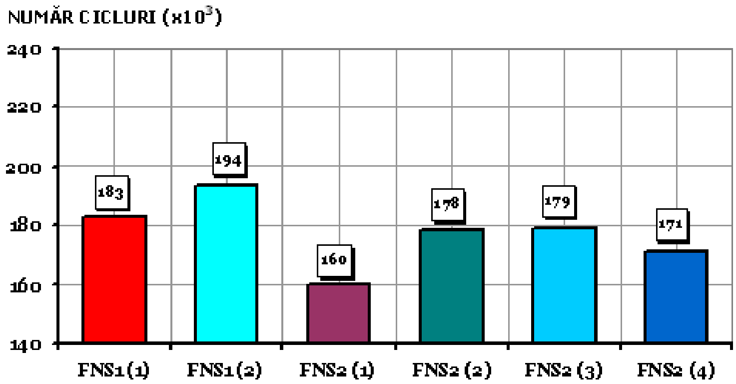

Fig. 9. Durability histograms (for the regime B)

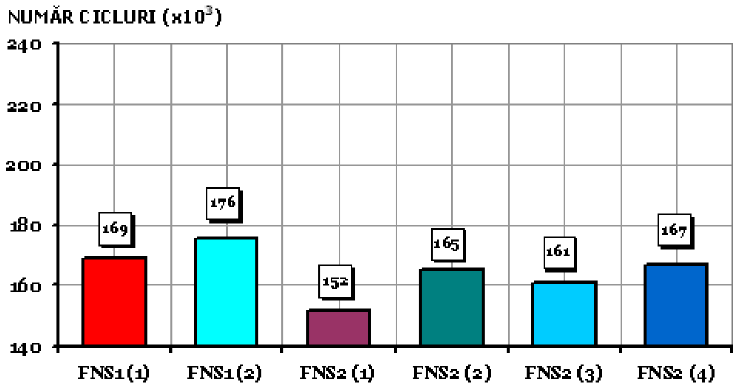

Fig. 10. Durability histograms (for the regime C)

Table 6. 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	$182 \cdot 10^3$	$171 \cdot 10^3$	$157 \cdot 10^3$

Table 7. The chemical composition and the hardness of the nodular irons 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

5. CONCLUSIONS

- 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).
- The curves of temperature variation, both on the surface of the cylinder and in the radial section are obtained experimentally, in a research laboratory belonging to the Faculty of Engineering Hunedoara.
- 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 six cast irons with nodular graphite from which the ring are manufactured, 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 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 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.
- 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.

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