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EXPERIMENTAL RESEARCH ON DURABILITY IN EXPLOITATION OF ROLLING MILL ROLLS

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Original scientific paper

The purpose of this work is to present some guidelines in the quality improvement of rolling iron rolls, aiming at increasing durability and safety in operation. The study analyses the influence of chemical composition on durability in exploitation of rolling mill rolls. The research also suggests solutions meant to increase the rolling mill rolls endurance in exploitation. *The research on durability in exploitation of rolling mill rolls represents an important scientific and economical issue.* These researches 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 research uses data collected from the industrial use at the *Iron and Steel Laboratory of the Faculty of Engineering - Hunedoara* as well as laboratory experiments carried out on an unique, complex and original installation. In this sense, the paper presents some results of a series of researches and experimentations of durability on testing lots through laboratory experiment, in distinct series, that represent the object of the laboratory research methodology. Although the manufacture of rolls is in constant improvement, the requirements for superior quality rolls have not yet been met, 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. In this sense, durability in exploitation is extremely important both for immediate practice and for the scientific research attributed to the cast-iron rolls.

Keywords: *experimental research, iron rolls, durability in exploitation, thermal fatigue*

Eksperimentalno istraživanje trajnosti u eksploataciji valjaoničkih valjaka

Izvorni znanstveni članak

Namjera ovog rada je predstaviti neke pravce vezane za poboljšanje kvalitete željeznih valjaoničkih valjaka, s ciljem povećanja trajnosti i sigurnosti u radu. Studija predstavlja detaljnu procjenu utjecaja kemijskog sastava na trajnost u eksploataciji valjaoničkih valjaka. Također, istraživanje sugerira rješenja kojima je cilj povećati izdržljivost valjaoničkih valjaka u eksploataciji. Istraživanje trajnosti u eksploataciji valjaoničkih valjaka predstavlja važan znanstveni i ekonomski problem. Ova istraživanja pokušavaju dati odgovore na većinu stvarnih problema vezanih za povećanje tvrdoće valjaoničkih valjaka. Oni su karakterizirani složenim sustavom pojave pukotina na površinskom sloju ili jednostavnim lomom, uslijed toplinskog šoka prouzročenog kontaktom vrelog metala s vodom hlađenim valjcima. Istraživanje koristi podatke prikupljene iz industrijske uporabe na *Iron and Steel Laboratory of the Faculty of Engineering - Hunedoara*, kao i laboratorijskim eksperimentima provedenim na jedinstvenoj, kompleksnoj i originalnoj instalaciji. U tom smislu, namjera rada je predstaviti neke rezultate niza istraživanja i ispitivanja trajnosti na ispitnim kockama, kroz laboratorijske eksperimente, u posebnim serijama, koje predstavljaju predmet metodologije laboratorijskog istraživanja. Proizvodnja valjaka se stalno usavršava, no zahtjevi za vrhunsku kvalitetu još uvijek nisu u potpunosti zadovoljni. U većini slučajeva, nedostatak kvalitetnih valjaka sprečava ostvarenje kvalitetnih ploča ili produktivnosti valjaonica za koju su predviđene. U tom smislu, trajnost u eksploataciji je vrlo aktualna, kako za neposrednu praksu, tako i za znanstvena istraživanja koja se odnose na valjke od lijevanog željeza.

Ključne riječi*: eksperimentalno istraživanje, željezni valjci, trajnost u eksploataciji, toplinski zamor*

1 Introduction
Uvod

Having in view the statistical data calculated for 10 years, the total consumption of rolling mill rolls represents 0,785…0,8 kg/tone of rolled steel. Nationwide, the 5 million tones steel being rolled every year represents a consumption of 4000 tones rolls, worth 6 million euro/year, which imposes large research with an important economic and scientific impact [1-6]. 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.

Currently, many aspects of the thermal regime of lamination are still not enough studied, and also, there are no efficient methods for the determination and adjustment of the rolls temperatures from the industrial rolling mills [1-6]. The intensification of the lamination process directly influences the durability of the rolls, these being the most solicited parts of machines from the whole ensemble of the lamination equipments. The technological processes of the rolls manufacture, as well as the quality of used materials have a quick extension, materialized in the worldwide market competition, through exceptional quality of rolls. In the context of market economy a new evolution in the area of scientific researches is necessary, with the purpose of modernization of the equipments and metallurgical plants, using the most efficient solutions for obtaining aggregates with performances to the level of world technique [1, 4-6]. The lack of detailed researches, theoretical and experimental, about the thermo-mechanical processes taking place during the plastic deformations between the rolling mills rolls, represents a factor that reduces the possibility of rational exploitation of rolling mills [1-4]. 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 to which are submitted the rolls or other elements of machines that work in constant (symmetrical) or variable (asymmetrical) thermal solicitation conditions.

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 exploitation. These researches approach the quality assurance of the rolling mills rolls from the viewpoint of the quality of materials, the feature that can define the duration and the safety in exploitation [1, 4].

The researches of durability in the exploitation of cast from cast-iron rolls present a scientific novelty and experimentally define an important chapter on thermal fatigue of rotating machine parts in variable temperature media. Hot rolling mills rolls operate in variable compound solicitations due to lamination process and they are repeated in regular intervals of time. All these phenomena are not taken into consideration in the classic calculus of rolls. If the study of the rolls resistance is extended upon their durability, the whole complex of tensions with mechanical-thermal influences can be considered. 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 to which are submitted the rolls or other elements of machines that work in constant (symmetrical) or variable (asymmetrical) thermal solicitation conditions.

The recommendations for the increase of the duration of exploitation and removal of the damages caused by accidental rupture of rolls from the stands of lamination, the attenuation of the rolls thermal fatigue, the avoidance of thermal shock and their rational exploitation are the actual issues that must be continuously researched [4,6-8]. This is the frame within which the research of the thermal fatigue phenomena is conducted, materialized in both technical reports whose beneficiary is the unit in which the rolls are exploited, and scientific papers that can develop the framework of scientific research. These research results lead to direct conclusions about the cast-iron rolls, and permit their comparison with the data about steel rolls, the area studied and thoroughly researched by specialists [1-6].

These results are of immediate practical utility for both the cast-iron rolling mills roll manufacturing industry, and the rolling sectors [4, 7, 8]. In this sense, these research results can be used by the foundries and the rolling mills sectors for quality assurance of rolls both in the phase of production and exploitation thus resulting, inevitably, in the quality assurance of produced laminates.

2
The experimental equipments
Eksperimentalna oprema

The research uses data collected from the industrial use at the *Laboratory of Iron and Steel of Hunedoara (Faculty of Engineering)*, as well as laboratory experiments carried out on a unique, complex and original installation [4-6].

Fig. 1 presents the construction plan of the installation for determining the durability of the hot rolling mill rolls. This installation provides the possibility of further studies and also the possibility to establish the durability in exploitation for all types of rolls used presently in industrial mills [1-6].

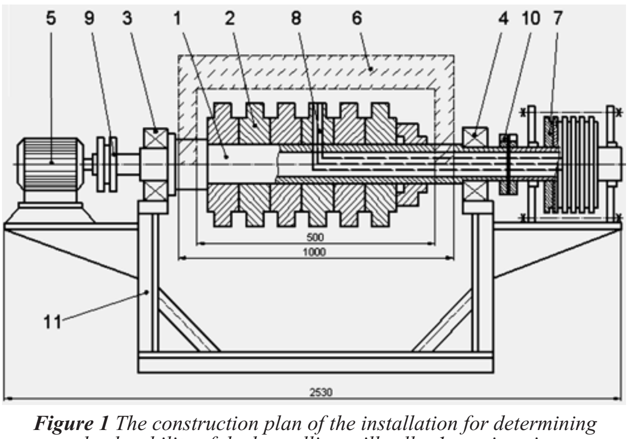

Figure 1 *The construction plan of the installation for determining the durability of the hot rolling mill rolls: 1 - main axis; 2 - experimental samples; 3, 4 - bearings; 5 - asynchrony electric engine; 6 - electric resistance furnace; 7 - thermo tension collector; 8 - pin; 9, 10 - couplings; 11 - metallic skeleton*
Slika 1 *Shema konstrukcije instalacije za utvrđivanje trajnosti valjaoničkih valjaka: 1 - glavno vratilo; 2 - eksperimentalni uzorci, 3, 4 - ležajevi; 5 - asinkroni elektro-motor; 6 – elektro-otporna peć; 7 - kolektor toplinske napetosti; 8 - igla, 9, 10 - spojke; 11 - metalni kostur*

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 the research in view, three armatures of specimens were made, each with six rings, every one made of nodular graphite iron used in the making of rolls in heavy section mills.

These rings were subjected 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 [2, 3, 4].

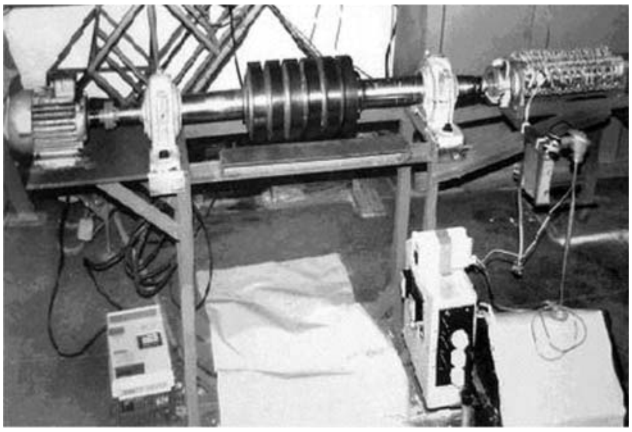

Figure 2 *Assembly of main axis and ring shaped samples, under durability tests*
Slika 2 *Sklop glavnog vratila i uzoraka u obliku prstena pri testovima izdržljivosti*

The durability research equipment is composed of the main axis (1), on which are attached the ring shaped experimental samples (2) cast from types of steel and iron intended for the casting of hot rolling rolls. The main axis is leaned on bearings (3) and (4), being driven by an asynchrony electrical engine (5), with a power of 2,2 kW, governed by a tri-phased frequency static converter. The main axis with samples is assembled directly to the electrical engine and the thermo tension collector through couplings (9) and (10). The entire system is placed on a metallic skeleton (11). The electrical furnace for heating of samples is mounted on the inferior side in the shape of a semi-circle with two electrical resistances (R1, R2), each composed of four blisters arranged in longitude, parallel with the main axis. Fig. 3 presents the construction scheme of the furnace, and Fig. 4 the inside setting of the resistance loops. The inside of furnace (1) (Fig. 3) contains the assembly of the ring shaped samples (2), made from roll necks which performed the rolling campaign. The

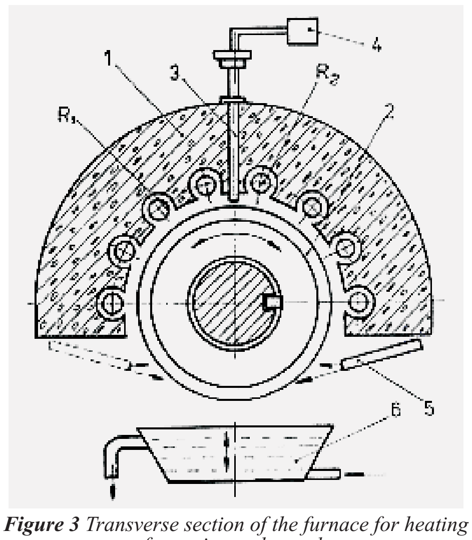

Figure 3 *Transverse section of the furnace for heating of experimental samples*
Slika 3 *Poprečni presjek peći za zagrijavanje eksperimentalnih uzoraka*

temperature of the environment inside the furnace is measured by thermocouple (3), connected to automaton (4), which shows the temperature values and controls the maintaining of the necessary temperature of 910 °C in the furnace. Fig. 4 presents the inside setting of the resistance loops.

Figure 4 *The setting of loops inside the electrical furnace*
Slika 4 *Postavka petlji unutar električne peći*

Figure 5 *The experimental rings and the assembly of conical pin fitted Pt-Pt/Rh thermo-couplings, prepared for installation in the ring sample*
Slika 5 *Experimentalni prsteni i sklop konične igle spojene Pt-Pt/Rh termoparovima, pripremljenim za instalaciju u prstenu uzorku*

During the experiments, after a certain number of stress cycles, the surface of the sharp sides of the rings shows 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. 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, 4, 9].

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 inertia response under a tenth of a second. These thermocouples measure temperature variation on the surface of the sample and the r = 0; 1,5 and 3,0 mm depths. They are presented together with the interior assemblage in Fig. 5.

3 Working regimes
Radni režimi

From the study of the thermal regime of the hot rolling rolls the minimal value was adopted for the rotation number of the tryouts constrained to durability test being as 30,6 rpm, producing the highest thermal fatigue because the thermal tensions appearing as the effect of temperature variations are maximal and after a relatively small number of rotations appear the first thermal fatigue cracks [4-6,9].

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

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

Based on the previously presented data, three experimental thermal regimes have been adopted, having the main elements presented in Tab. 1. The order of the experiments was regime A, B and C. During the experiments the temperature of the electric furnace medium was permanently registered in stationary regime (910 °C) and the temperature variations to one revolution of the rings on the exterior surface as well as in the superficial layer at Δr = 1,5 and 3 mm depth.

Table 1 *The experimental regimes*
Tablica 1 *Eksperimentalni režimi*

The characteristic elements from the experimental regime	Experimental regimes		
	A	B	C
Rotation number of the tryouts mounted on the main axle, rpm	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

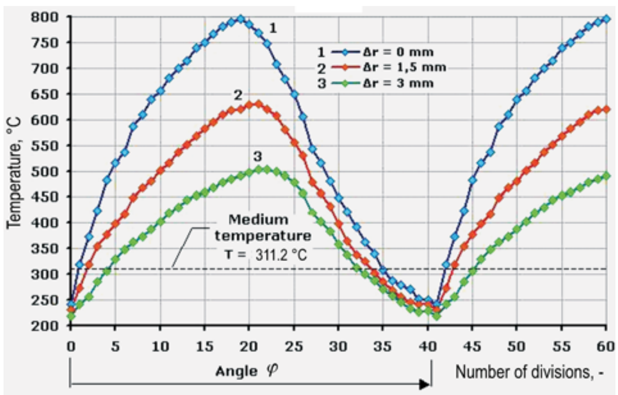

Figure 6 *The cyclic temperature variations in points, on the surface and in the superficial layer (A)*
Slika 6 *Ciklične promjene temperature u točkama, na površini i u površinskom sloju (A)*

***Table 2** Cyclical temperature variation on the surface and in the superficial layer of samples, exploited in regime A, with n* = 30,6 rpm*, at a furnace temperature* (910 ± 10 °C)
***Tablica 2** Ciklična promjena temperature na površini i u vanjskom sloju uzoraka, eksploatiranih u režimu A, s n* = 30,6 okr/min*, na temperaturi peći* (910 ± 10 °C)

No.	The temperature variations, °C at Δ*r*, mm			No.	The temperature variations, °C at Δ*r*, mm		
	0	1,5	0		0	1,5	3
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

***Table 3** Cyclical temperature variation on the surface and in the superficial layer of samples, exploited in regime B, with n* = 30,6 rpm*, at a furnace temperature* (910 ± 10 °C)
***Tablica 3** Ciklična promjena temperature na površini i u površinskom sloju uzoraka, eksploatiranih u režimu B, s n* = 30,6 okr/min*, na temperaturi peći* (910 ± 10 °C)

No.	The temperatures variations, °C at Δ*r*, mm			No.	The temperatures variations, °C at Δ*r*, mm		
	0	1,5	3		0	1,5	3
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

During the experimental process of durability at thermal fatigue the electronic calculus technique was utilized using a program working on one IBM PC computer, for ADAM–4018 modules at the entrance and ADAM–4520 converter at the exit. The cyclic temperature variations have been thus registered in points, at the surface and in the superficial layer, the obtained results from the file being shown in Tab. 2, 3 and 4 and the diagrams in Fig. 6, 7 and 8.

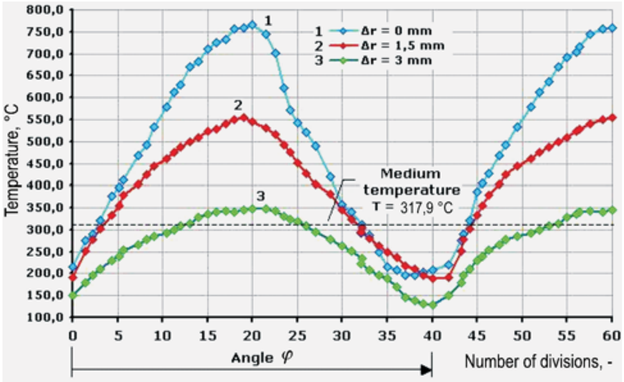

***Figure 7** The cyclic temperature variations in points, on the surface and in the superficial layer (B)*
***Slika 7** Cikličke promjene temperature u točkama, na površini i u površinskom sloju (B)*

***Table 4** Cyclical temperature variation on the surface and in the superficial layer of samples, exploited in regime C, with n* = 30,6 rpm*, at a furnace temperature* (910 ± 10 °C)
***Tablica 4** Ciklična promjena temperatura na površini i u površinskom sloju uzoraka, eksploatiran u režimu C, s n* = 30,6 okr/min*, na temperaturi peći* (910 ± 10 °C)

No.	The temperatures variations, °C at Δ*r*, mm			No.	The temperatures variations, °C at Δ*r*, mm		
	0	1,5	3		0	1,5	3
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

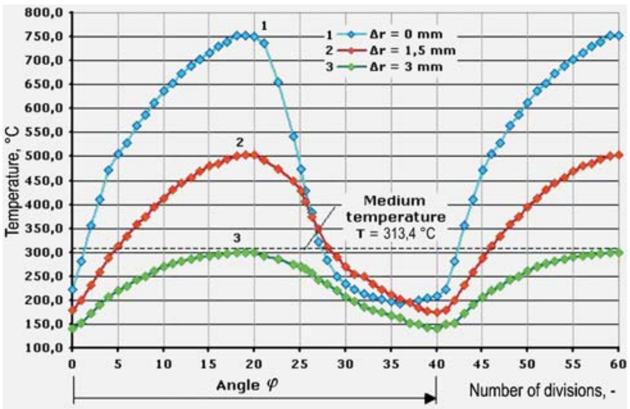

***Figure 8** The cyclic temperature variations in points, on the surface and in the superficial layer (C)*
***Slika 8** Cikličke promjene temperature u točkama, na površini i u površinskom sloju (C)*

4 Analyses and Results
Analiza i rezultati

Analyzing the temperature variation diagrams considered as isochronal estates, during the thermal fatigue experimental estates of the tryouts in A, B and C regimes it was observed that the highest registered temperature on the exterior surface of the rings was 776,7 °C (for $\Delta r = 0$ mm), in the A regime when the cooling was effected in open air.

In the B regime, having a recycling water bath cooling system, the temperature variation curves had a less accentuated downgrade in the area of the cooling angle, reaching the maximal temperature of 767,4 °C on the rings surface (for $\Delta r = 0$ mm), and the minimal temperature was 152 °C (for $\Delta r = 3$ mm).

In the C loading regime where the carbon-dioxide ice was blasted in by a distributive collector, in the cooling area the temperature variation curves became even more accentuated, the maximal temperature on the rings surface being 757,2 °C (for $\Delta r = 0$ mm), and the minimal temperature in the superficial layer 140,6 °C (for $\Delta r = 3$ mm).

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

As a general observation for all the three registered diagrams, the temperature variation curves' peaks have a certain displacement on the abscissa, the fact that indicates the heat transmitting time in the rings mass, respectively in the superficial layer. The situation is similar in a reverse way for the cooling process too, being more accentuated in the B and C regimes, when the rings' surface cools faster so that the temperature of the superficial layer at the $\Delta r = 1,5$ mm depth is higher than that on the surface.

Table 5 *Synthesis of the characteristic data for cyclical variation of temperature from the superficial layer of the ring typed tryout experimentally exploited in A, B, C regime*
Tablica 5 *Sinteza karakterističnih podataka za cikličnu promjenu temperature, površinskog sloja pokusnog prstena eksperimentalno eksploatiranog u A, B, C režimu*

Diagram of the cyclical variation of temperatures, according to experimental exploitation regime	Depth of superficial layer, Δr, mm	Limit temperature variation, °C	
		Maximal	Minimal
Experimental stress "A" regime (see Fig. 6)	0	776,7	239,2
	1,5	620,2	231,2
	3,0	499,2	219,2
Experimental stress "B" regime (see Fig. 7)	0	767,4	195,2
	1,5	505,0	180,3
	3,0	348,3	152,1
Experimental stress "C" regime (see Fig. 8)	0	757,2	204,0
	1,5	505,0	180,3
	3,0	292,6	140,6

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 ø250 mm maximal diameter on each ring assembled in the packing, after a certain determined number of thermal loading cycles. The visualizations, performed in order to observe the thermal fatigue cracks, were made twice per day, calculating the number of cycles passed after each of the visualizations. After the experimental exploiting of the durability tests evaluated in thermal loading cycles, durability histograms were made for each loading regime and for each mark of the studied material, the results being presented in Fig. 9, Fig. 10 and Fig. 11 (synthesized in Tab. 6). Also, Tab. 7 presents the chemical composition and the hardness of the nodular irons included in the study [4, 9].

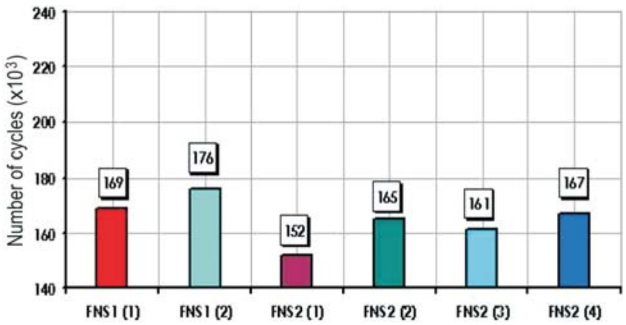

Figure 9 *Durability histograms (for the regime A)*
Slika 9 *Histogrami trajnosti (za režim A)*

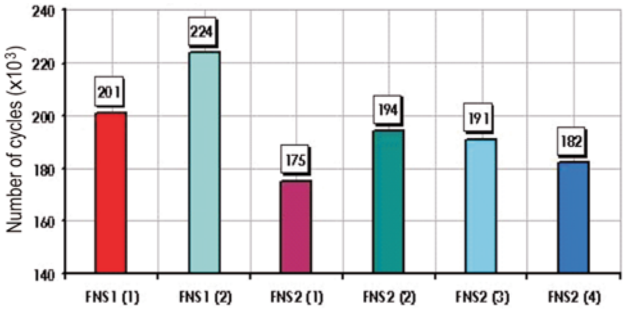

Figure 10 *Durability histograms (for the regime B)*
Slika 10 *Histogrami trajnosti (za režim B)*

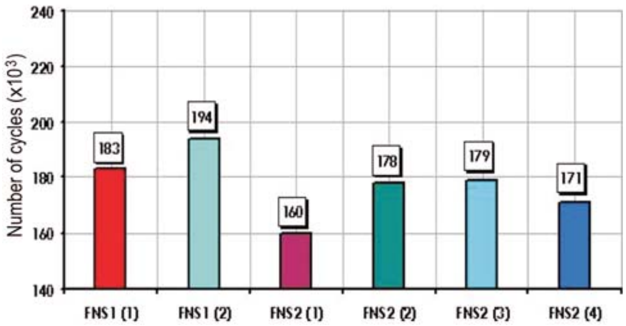

Figure 11 *Durability histograms (for the regime C)*
Slika 11 *Histogrami trajnosti (za režim C)*

Table 6 *The number of thermal cycles and cyclical thermal solicitation regimes*
Tablica 6 *Broj toplinskih ciklusa i ciklični toplinski režimi*

No. of rings	Type	Number of thermal cycles / The cyclical thermal solicitation regimes		
		A	B	C
1.	FNS1	201×10^3	183×10^3	169×10^3
2.	FNS1	224×10^3	194×10^3	176×10^3
3.	FNS2	175×10^3	160×10^3	152×10^3
4.	FNS2	194×10^3	178×10^3	165×10^3
5.	FNS2	191×10^3	179×10^3	161×10^3
6.	FNS2	182×10^3	171×10^3	157×10^3

5 Conclusions
Zaključci

The laboratory experiments demonstrated that an optimal, determined chemical composition could assure both the wear resistance (through hardness), and the proper behavior in the thermal fatigue solicitations. In this sense,

***Table** 7 The chemical composition and the hardness of the nodular irons included in study*
***Tablica** 7 Kemijski sastav i tvrdoća nodularnog lijev uključenog u elaborat*

FNS2	FNS2	FNS2	FNS2	FNS1	FNS1	TYPE	
1. 2. 3.	1. 2. 3.	1. 2. 3.	1. 2. 3.	1. 2. 3.	1. 2. 3.	No.	
3,16	3,21	3,20	3,34	3,40	3,41	C	Chemical composition, %
1,79	1,67	1,91	1,79	1,94	2,19	Si	
0,61	0,54	0,54	0,58	0,67	0,72	Mn	
0,024	0,018	0,011	0,017	0,015	0,015	S	
0,121	0,116	0,117	0,106	0,148	0,148	P	
0,81	1,46	1,44	1,12	2,11	2,08	Ni	
0,39	0,65	0,41	0,30	0,68	0,72	Cr	
0,21	0,24	0,31	0,71	0,27	0,23	Mo	
367	406	393	457	342	338	body	Hardness, HB
310	330	365	390	270	264	neck	

the following conclusions can be 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 smallest number of stress cycles (heavy regime).
- the curves of temperature variation, both on the surface of the rolls and in the radial section are obtained experimentally in the research laboratory belonging to the Faculty of Engineering – Hunedoara.
- the paper presents some results of a series of researches and experimentations of durability on testing lots through laboratory experiment, in distinct series, that represent the object of the laboratory research methodology. In the experiments three experimental thermal regimes have been adopted, and is demonstrated, on the path of the experiment of laboratory, that a chemical composition can assure both the hardness of the rolls, and a proper behavior in the thermal fatigue conditions.
- analyzing the results, the cast irons of the rings no. 2 and no. 1 that are ones with the class 1 of hardness (FNS1) had best behavior to the thermal fatigue, these supporting 224 000 cycles in the regime, respectively 201 000 cycles for the same regimes of solicitation; the most dissatisfactory behavior was shown by cast-iron of the ring no. 3, from class 2 of hardness (FNS2); the irons of the rings no. 4 and no. 5 behaved both in satisfactory ways.

The research on the hot rolling mill rolls durability in exploitation 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. 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.

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