Approaches of the Experimental Durability Researches upon the Exploitation of Rolling Mill Rolls

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Abstract: *The researches on the durability in exploitation of hot rolling mill rolls represent an important scientific and economical issue. The study represents a detailed approach of the influence of various technological factors on the durability in exploitation of rolling mill rolls made of different steel and pig iron grades and suggest solutions meant to increase the durability of the rolls in exploitation. The purpose of this work is to increasing of durability and safety in operation.*

Key words: *durability in exploitation, thermal fatigue, thermal cycles, steel and iron rolls.*

INTRODUCTION

The classic methods for evaluating the durability of rolls do not provide an answer to many of the phenomena accruing in the rolling process, between rolls and laminate. These methods do not take into consideration the highly important thermal influences, which constitute one of the fundamental causes leading to the destruction of hot rolling mill rolls and, also, may reach considerable values that can be observed only through experiments. The lack of detailed, theoretical and experimental research upon thermo – mechanical processes that take place during plastic deformation in rolling rolls, constitutes a factor, which reduces the possibilities of rational exploitation in rolling mills.

The rolls are applied to thermal tensions that are variable, complex, with extremely marked influences. Therefore, to intensify the rolling processes we need to observe the durability limits, with thermal tensions produced in symmetrical and asymmetrical temperature fields, at a large number of stress cycles. To this purpose it is necessary to know as accurately as possible the type of stress, the materials, and a detailed characterizes evaluation, to determine exploitation timing and to compare with previously established values. The study represents a detailed approach of the influence of various technological factors on the durability in exploitation of rolling mill rolls made of different steel and pig iron grades and suggests solutions meant to increase the hardness of rolling mill rolls in exploitation.

THE EXPERIMENTAL RESEARCH

Hardness testing is done on a series of rings, achieved from the rolls' axles resulted from the industrial operation and which accomplished the rolling drives. In experiments these rings are subject to different conditions of cyclic thermal requirements, that during a rotation, they turn to heat in a furnace containing electric resistors, at different imposed temperature on the one hand and on the other hand, they turn cold in different environments: air (A regime), water (B regime) and carbonic snow jets (C regime).

In the experimentally installation for the research on the durability in exploitation of the steel and iron marks, until the appearance of the thermal fatigue cracks is presented. With a view to choosing the materials on which hardness testing is about to be done, and respectively the types of steel and cast iron frequently used at the achievement of rolling rolls, it was necessary the studying of constructive parameters and the features on the behaviour in operation of all rolls found in the industrial housing of a rolling-mill from an iron and steel combine, which has a rolling capacity of over 2 million tons of steel per year. As to the types of steel and cast iron used at the achievement of rolls, these are limited and refer to six qualities (three steel and three cast iron) as well as: *65VMoCr15* – steel used to manufacture rolls from semifinished mills; *55VMoCr12* – steel used to manufacture rolls from semi-finished mills; *90VMoCr12* – steel used to manufacture rolls from heavy section mills; *OTA3* – Steel used to manufacture rolls from heavy, medium and light mills; *FNS 2* – iron used in the making of rolls in heavy section mills; *FD2* - iron used in the making of rolls in heavy section mills and light section and wire mills.

From the study of the durability of the hot rolling rolls, where have been registered isochronal diagrams representing the rolling rolls temperature variations, corresponding to a two circular measure angle, resulted that the maximal asymmetrical temperatures appears at diminishing rolling speed, respectively diminishing rotation numbers of the rolls. Once with the increment of the rotation numbers of the rolls, at high rolling speeds decrease the asymmetric temperature fields so; decrease also the calibers thermal fatigue loading. On these bases, we chose the minimal value for the rotation number of the tryouts constrained durability test being as 35.7 rot/min, producing the highest thermal fatigue because the thermal tension appearing as effect of temperature variations are maximal and after a relative small number of rotations, appear the first thermal fatigue cracks.

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. In this way has been registered the cyclic temperature variations in points, at the surface (Δr = 0) and in the superficial layer (Δr = 1.5 and 3.0 mm). 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 1.*

In stress regime A, the materials under study resisted longest at stress cycles, until the first thermal fatigue cracks appeared, and this regime is called loading regime. In stress regime B, the first thermal fatigue cracks appeared in a smaller number of stress cycles and this is a medium regime. In stress regime C, the thermal fatigue cracks appeared at the lowest number of stress cycles and it is called a heavy regime. The durability histograms for the steel and cast iron marks are presented in *figures 1, 2* and *3*.

Table 1. The minimal and maximal level for cyclical variation of temperature after the isocronal diagrams

Depth of the superficial layer Δr [mm]	The diagram of cyclic temperature variations in working regime A		The diagram of cyclic temperature variations in working regime B		The diagram of cyclic temperature variations in working regime C	
	The determinate temperature variation, [^{0}C]					
	Maximal	Minimal	Maximal	Minimal	Maximal	Minimal
0	809.7	265.2	796.4	203.1	766.3	197.1
1.5	639.5	250.4	543.7	193.6	504.6	175.3
3 ,0	508.1	233.5	338.3	162.7	298.4	138.8
Number of rotations n = 35.7 rot/min $\varphi_{\hat{i}} = \varphi_e = 180^0 = 2\pi$ rad						

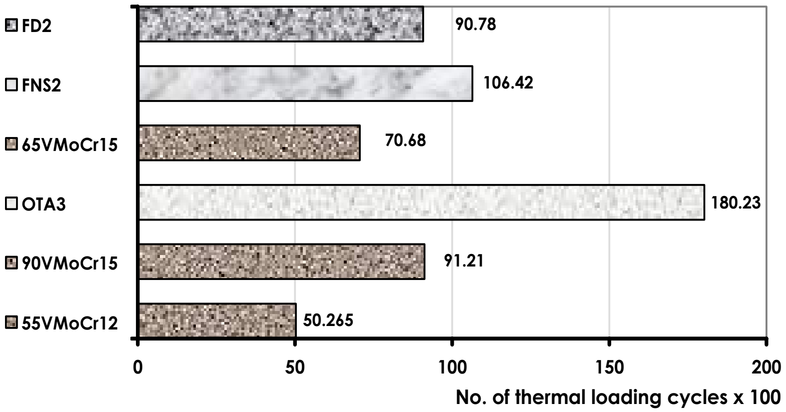

Figure 1. Durability histograms for „A" thermal regime

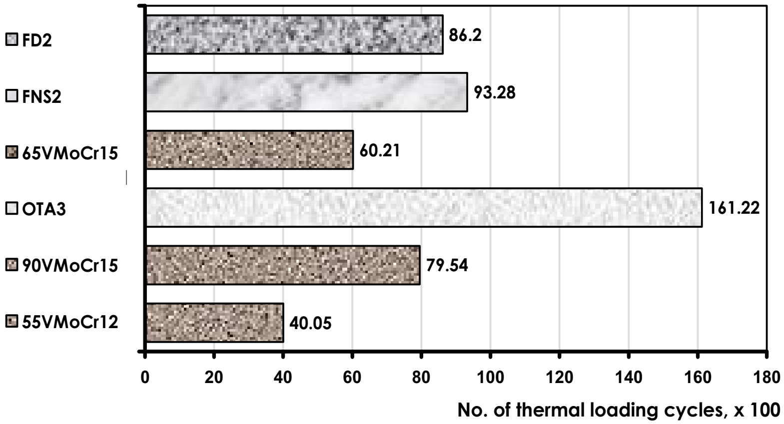

Figure 2. Durability histograms for „B" thermal regime

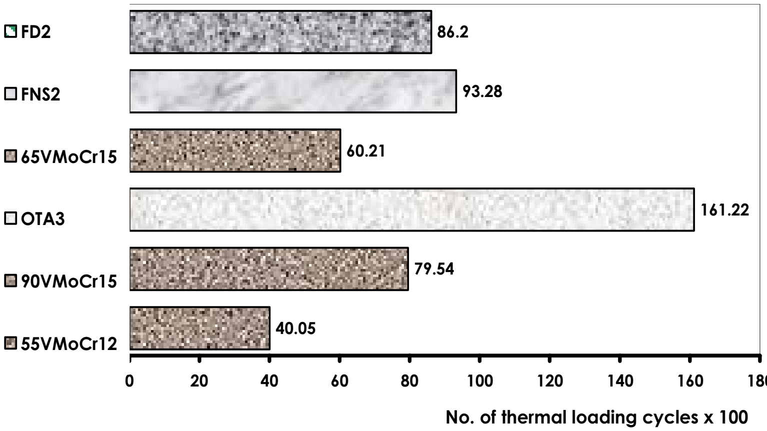

Figure 3. Durability histograms for „C" thermal regime

After analyze the durability histograms the synthesis for number of thermal loading cycles aiming by the appearance of the first thermal fatigue cracks is presented in *Table 2*.

Table 2. The synthesis of thermal loading cycles aiming by the appearance of the first thermal fatigue cracks

No.	The steel and the cast iron marks	Number of thermal loading cycles		
		Working regimes A	Working regimes B	Working regimes C
1.	55VMoCr12	5265	4005	3647
2.	90VMoCr15	9121	7954	7110
3.	OTA 3	18023	16122	14865
4.	65VMoCr15	7068	6021	5206
5.	FNS2	10642	9328	8688
6.	FD2	9078	8620	7469

If analyze *Table 2* we can see that the type of stress which gave the best results regarding stability to thermal fatigue – studied in stress regime C – is the *OTA 3* steel type, underwent to 14865 cycles until the first cracks of thermal fatigue. Other types of steel *55VMoCr12* and *90VMoCr15* underwent relatively well to the stress of thermal fatigue in stress regime A and acceptably well in stress regimes B and C. In the case of the two types of iron used in experimental research a better behavior was noticed at *FNS2* which underwent to 8688 cycles in stress regime C, until the first cracks of thermal fatigue. Iron type *FD2* behaves acceptably and is used to produce hard rolls from finishing stands.

EVALUATING THE RESULTS

In order to evaluate the results of the researches upon the experimental rings durability's to thermal fatigue and the extension of comparative results with the durability's rolls exploitation from the industrial bar mills, is imperative to determine the temperature fields variations also in un-dimensional form. So, the temperature field's variations during both the experimental rolling, and during the durability's experimentations of the rings, will be calculated in specific un-dimensional temperature variations, which is determined with relation (1).

$$\theta = \frac{t - t_{min}}{t_{max} - t_{min}} \quad (1)$$

in where: θ – specific temperature, it is a parameter, it`s values are between 0 and 1; t – variable temperature in the roll; t_{min} – minimum temperature; t_{max} – maximum temperature;

If the variable temperature in the roll is $t = t_{min}$, in this conditions θ = 0 and for $t = t_{max}$, θ = 1. The dimensionless radius in the quaquaversal section of the rolls is determined with relation (2).

$$\rho = \frac{r}{R} \quad (2)$$

in where: ρ – dimensionless radius in the quaquaversal section of the rolls which change in 0 and 1; r - mensuration radius in the section quaquaversal section of the rolls; R – maximum radius in the quaquaversal section of the rolls. For r = 0, ρ = 0 and if r = R, ρ = 1.

The medium values of the temperature variations $\overline{\theta}$ will determine with Simpsons as well as represent the integral of the function that describes the temperature field.

The use of the specific temperature variations and the specific radius in un-dimensional form is necessary because the temperature variations in the rolls are smaller in comparison to the thermal variations from the experimental rings. These variations were intentionally increased in order to decrease the experimental time until the appearance of the first cracks produced by the overload of the thermal regimes.

In this sense, the number of rings real thermal fatigue solicitation cycles would have been bigger in the case of similar solicitations then in the case of the experimental rolling. So, in order to establish the real number of solicitation cycles, it is imperative to calculate the thermal coefficient K_T, which is determined with relation (3).

$$K_T = \frac{\overline{\overline{\theta}}_{experimental rolling - experimental rings}}{\overline{\overline{\theta}}_{experimental rolling}} \quad (3)$$

in which: $\overline{\overline{\theta}}_{experimental rolling}$ – mean specifically temperature, middle of the three variations level of temperature (Δr = 0; 1.5; 3.0 mm) from the experimental rolling diagram with n = 35.7 rot/min; $\overline{\overline{\theta}}_{experimental rings}$ – mean specifically temperature, middle of the temperature variations from the diagram of rings experimental thermal solicitation.

Table 3. The synthesis of the temperature variation in the experimental rolling with n = 35.7 rot/min

Depth of the superficial layer Δ r [mm]	Particular radius ρ	Determinate temperature					
		Maximum		Medium		Minimum	
		[°C]	θ_{max}	$\bar{t}$ [°C]	$\bar{\theta}$	[°C]	θ_{min}
0	1	524,8	1	169,5	0,29738	128,5	0
1.5	0,9923469	362,9	1	172,4	0,30320	126,7	0
3.0	0,9846938	211,6	1	115,33	0,18978	84,0	0
$\bar{\bar{t}}$, $\bar{\bar{\theta}}$ - average temperature				152,41	0,263453	-	-

The synthesis of the temperature variation registered to the experimental rolling with n = 35.7 rot/min is presented in *Table 3*. Through similar calculus (presented in *Table 3*) are determined the specific temperature, mean of middle values $\bar{\bar{\theta}}$, after the processing the diagrams corresponding the experimental regimes A, B and C, with n = 35.7 rot/min. The results are presented in *Table 4*, among the values of the thermal coefficient, K_T.

The number of thermal solicitation cycles in the regimes A, B and C, is smaller then the real number that would have been obtained if the loading temperature were identical with the experimental rolling temperature. In order to determine the real solicitation cycles number until the appearance the first thermal fatigue cracks, we have to multiply the experimental cycles number with the values of the thermal coefficient, K_T, obtained through calculus for each experimental regime, *Table 4*. The real solicitation cycles number until the appearance the first thermal fatigue cracks in the works regime A, B, C calculated with the values of the thermal coefficient, $K_{T,}$ are presented in *Table 5*.

Table 4. The determination of the thermal influence coefficient K_T for the level of the cyclical variations of temperature under the working regimes

The specific average temperature in the experimental rolling $\bar{\bar{\theta}}_{rolling} = 0,263453$		
The values of the specific average temperature, $\bar{\bar{\theta}}$, calculated for the A, B, C working regimes		
Working regime A	Working regime B	Working regime C
$\bar{\bar{\theta}}_A = 0,556759$	$\bar{\bar{\theta}}_B = 0,529776$	$\bar{\bar{\theta}}_C = 0,511069$
Thermal influence coeficient		
$K_{TA} = \frac{0,556759}{0,263453} = 2,11331$	$K_{TB} = \frac{0,529776}{0,263453} = 2,01089$	$K_{TC} = \frac{0,511069}{0,263453} = 1,93988$

Table 5. The real solicitation cycles number until the appearance the first thermal fatigue cracks in the works regime A, B and C calculated with the values of the thermal coefficient, K_T

No.	The steel and cast iron marks	The real solicitation cycles number until appearance the first thermal fatigue cracks		
		Working regime A	Working regime B	Working regime C
		The values of the thermal influence coeficient		
		$K_{T-A} = 2,11331$	$K_{T-B} = 2,01089$	$K_{T-C} = 1,93988$
1.	55VMoCr12	11118.1	8053.6	7074.7
2.	90VMoCr15	19275.5	15994.6	13792.5
3.	OTA3	38088.1	32419.5	28836.3
4.	65VMoCr15	14936.8	12107.5	10099.0
5.	FNS2	22451.8	18757.5	16853.6
6.	FD2	19184.6	17333.8	14488.9

To compare the rings durability's, expressed in number of thermal cycles, with the durability's of the industrial exploitation of rolls, we have to compare each analyzed type of materials (steels and irons). Therefore, we transform the quantity of rolled materials expressed in product-tones on caliber into linear meter of finite products, and through there division at rolls caliber circumference, we obtain the number of thermal solicitation cycles of the industrial rolls.

Table 6. The mean values of durability's in the industrial exploitation, comparative with the real values of durability's, obtained in the research of the representative types steel and iron thermal solicitations

No.	The steel and cast iron marks	The medium number of thermal loading cycles for the experimental sample after the working regimes A, B şi C	The medium number of thermal loading cycles for the industrial rolling mills
1.	55VMoCr12	8748.8	6120.61
2.	90VMoCr15	16354.2	10881.02
3.	OTA3	33114.6	22428.15
4.	FNS2	19354.0	4721.85
5.	FD2	17002.2	25654.51

The mean values of durability's in the industrial exploitation, expressed in thermal solicitation cycles, are presented in *Table 6*, comparative with the real values of durability's, obtained in the research of thermal solicitations of the representative types steel and iron, used in the hot rolling rolls making process.

CONCLUSIONS

Analyzing the results in the previous paragraph, one can notice that:

- for the steel grades under consideration, respectively *55VMoCr12, 90VMoCr15* and *OTA3*, the hardness values are relatively similar.
- under industrial work conditions, hardness values are smaller than in laboratory, because of the influence of the mechanical effects, such as friction between grooves during the rolling process.
- for steel grade *65VMoCr15* industrial hardness has not been studied, as this steel grade is used for the manufacturing of rolling rolls used in the semi-finished parts rolling train, which at present is out of use and in conservation.
- the mean hardness of rolls made of cast iron *FNS2* is, under industrial exploitation, 9.09 times smaller than the mean hardness obtained experimentally on the samples tried for thermal fatigue. In this situation, we had to analyze the quality of rolls made of this grade of cast iron and we discovered that most of them had manufacturing fails, among which excessive porosities and faulty structures. In this sense, one can notice the fact that porosities have a significant influence on roll hardness under industrial rolling conditions, but they have no influence whatsoever upon the hardness of experimental samples.
- the hard cast iron *FD2*, used in manufacturing rolling rolls for the intermediary and finishing train of the small section rolling train, gave very good results under industrial exploitation, its mean hardness being 15088 times higher than on experimental sample rings.

The differences of mean hardness are fully justified, as we have determined the experimental values of hardness under work conditions A, B and C at a rotation speed of 35.7 rot/min, and the industrial rolls of the intermediary and finishing stands of the small section rolling mill had a rotation speed of 266…575 rot/min, which corresponds to a speed coefficient K_v = 6.33…16.106 that increases the number of thermal fatigue stress cycles up to the appearance of the first specific fissures.

In this situation, we can conclude that for relatively small rolling rates, temperature variations are higher and the phenomenon of thermal fatigue is more accentuated. At high rolling rates, where the number of rotations is significant, reaching in this case 266…575 rot/min, temperature variations are small and thermal fatigue is dimmed, while the number of thermal fatigue stress cycles increases up to the appearance of the first fissures, specific to this phenomenon. The results of these researches allow an extension of the studies to other steel and cast iron grades that show a higher strength and stability to thermal fatigue, which offers rolling rolls a higher endurance in exploitation.

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