LABORATORY RESEARCHES UPON THE THERMAL FATIGUE OF THE ORGANS OF MACHINES IN MOVEMENT OF ROTATION, IN VARIABLE TEMPERATURE MEDIUMS

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ABSTRACT

The researches of durability in the exploitation of cast-iron rolls define experimentally an important chapter from the thermal fatigue of the organs of machines in the movement of rotation, in variable temperature mediums. The researches on the durability in exploitation of hot rolling mill rolls represent an important scientific and economical issue. This paper presents original experimental equipment by the help of which the durability of hot rolling mills can be studied. This experimental equipment permits the evaluation of exploitation durability for hot rolls by studying the thermal fatigue phenomenon which appears in the case of machine components. The exploitation durability is evaluated through thermal fatigue cycles up to crack point due to thermal fatigue for each condition and each type of studied material. 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 durability of the rolls in exploitation.

Keywords: organs of machines, thermal fatigue, durability, temperature mediums

1. INTRODUCTION

The rolling mill rolls are the parts most subjected to wear in the rolling trains and they represent a consumption of 0.8 kg/tone of rolled steel. Nationwide, 4.5 million ton steel is being rolled every year. This represents a consumption of 3,600 tone rolls, which imposes researches with an important economic and scientific impact. It is noticeable that approximately 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. The intensification of the lamination process directly influences the rolls durability, these being the most solicited organs of machines from 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 worldwide market competition, through exceptional qualities of rolls. The different high alloy ferrous products currently used in the manufacture of these rolls define an important chapter from the quality assurance of the industrial products.

Poverty of detailed researches, theoretical and experimental, about the thermo-mechanical processes take place during the plastic deformations between the rolling mills rolls, represents a factor that reduces the possibility of rational exploitation of rolling mills. In the context of market economy is necessary a new evolution in the area of scientific researches, in 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.

The durability in exploitation of the rolling mill rolls 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 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. All these phenomena, which are more or less emphases depending on the type 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-thermal influences.

Hot rolling mill rolls are the parts most subjected to wear in the rolling trains because the incandescent rolled material is deformed between the water cooled rolls, at temperatures of 1100…1150^{0}C. Hot rolling mills rolls work the in the variable compound solicitations, due to lamination process and which repeat to regular intervals of time. 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. These rolls must be able to carry out extreme actions: very high thermal stresses and wear, along with mechanical stresses due to normal rolling loads. These actions lead to the development of cracks, which means that sufficiently high fracture toughness is also an important requirement. Our researches are trying to give answers to most actual problems related to the increase of rolling mill rolls quality.

2. MATERIALS and METHODS

The researches use data collected from the industrial use at the Iron & Steel Integrated Plant of Faculty of Engineering Hunedoara (Romania), as well as laboratory experiments carried out on a unique, complex and original installation. Figure 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 studiers and also to establish the durability in exploitation for all types of rolls used presently in industrial mills.

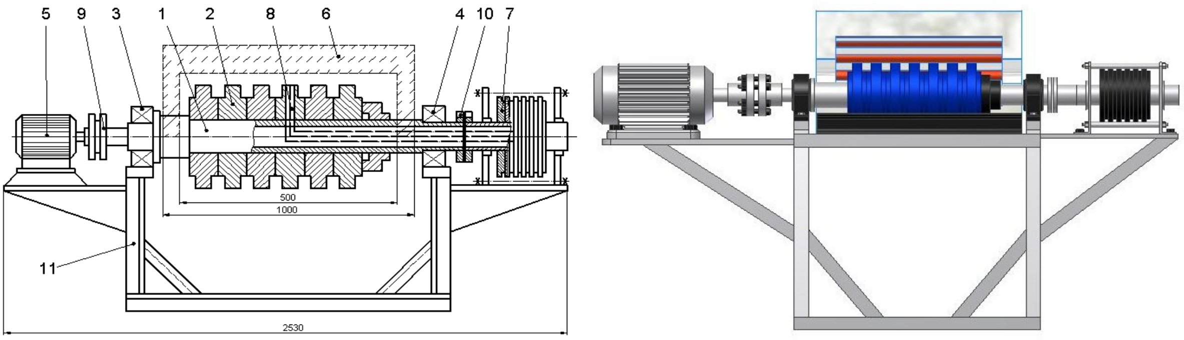


Figure 1 The construction plan of the installation for determining the durability of the hot rolling mill rolls. 1. main axis; 2. experimental rings; 3,4. bearings; 5. asynchrony electric engine; 6. electric resistance furnace; 7. thermo tension collector; 8. pin; 9, 10. couplings; 11. metallic skeleton

The experiments are made on groups of six rings, with a 250 mm exterior diameter, carried out from the studied types of industrial rolls. Having in view the research, three armatures of specimens were made, each with six rings and every ring made of the following materials:

– steel used to manufacture rolls from semi-finished mills (type 65 VMoCr15);
– steel used to manufacture rolls from heavy section mills (type 55 VMoCr12);
– steel used to manufacture rolls from heavy section mills (type 90 VMoCr15);

– steel used to manufacture rolls from heavy, medium and light section mills (type OTA3);
– iron used in the making of rolls in heavy section mills (type FNS2);
– iron used in the making of rolls in heavy and light section and wire mills (type FD2).

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. 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. 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 Figure 2.

Figure 2 Assembly of conical pin fitted Pt-Pt/RH thermocouplings

The heating furnace of the experimental rings is composed of refractory concrete casing, with a semicircular shaped inferior part and two electrical resistances, each of them with four loops. The diameter of the resistance wire is of 2.5 mm, the section of 4.907 mm^2 and the spiral diameter of D = 22 mm.

Figure 3 presents a scheme for the functioning and thermal fatigue in the durability equipment. In light working conditions, heating can be performed with one resistance, while in heavy working conditions, the heating of the rings is made with both resistances, in an angle rotation interval of $\varphi = \pi$ radians. If the heating is performed with one resistance, then the heating area comprises a 90^0 angle from the furnace's circumference, while for a simultaneous functioning of both resistances the heating takes place on the entire interval of the furnace semicircle, which corresponds to an 180^0 angle from the rings' circumference.

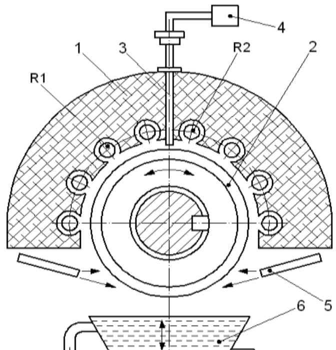


Figure 3 Transversal section through a sample heating furnace and ring axis

The heating time is depends on the engine's number of rotations, respectively ring tryout branch. They increase in heat at every rotation of the axis in the area of the furnace and then cool in different medium outside it (the inferior side). The control command station, with an electrical automat for heating the samples to establish and maintain a certain temperature necessary inside the furnace. The temperature is measured with thermocouple (3), to which it can be imposed, through automatic command, the temperature limit to be maintained during the experiments, this limit having a maximum value of 1000°C.
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. The results are to be compared with those in the industrial exploitation in the Rolling Mills sectors.
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°±100°C, but the experiments were effectuated at 910°±100° 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	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 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.

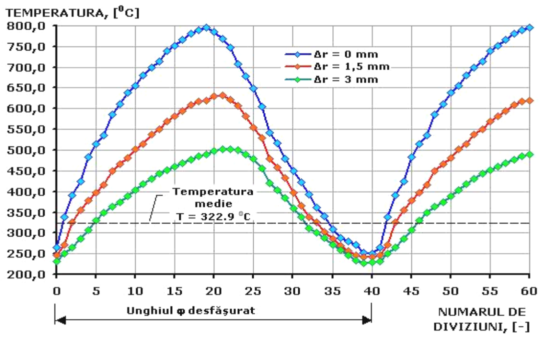
3. RESULTS and DISCUSSIONS

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 materials, aiming by visualization the appearance of the first thermal fatigue cracks. These values are compared with the results from another series of experiments.
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 795.3°C, 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

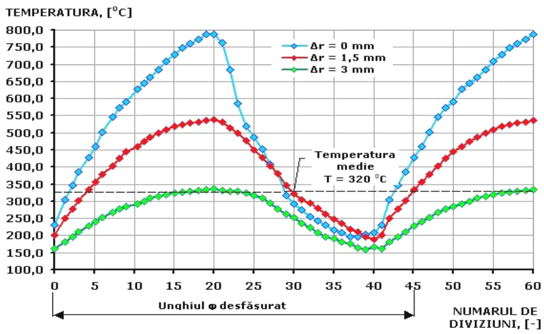
downgrade in the area of the cooling angle, reaching the maximal temperature on the rings surface 788.5°C, and the minimal temperature between 160...195.2°C. In the C loading regime was used carbon-dioxide ice blasted in by a distributive collector, the temperature variations curves becoming, in cooling area, even more accentuated, the maximal temperature on the rings surface being 762.6°C, and the minimal temperature in the superficial layer 140°C. 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 2.

Table 2 Synthesis of the characteristic data for cyclical variation of temperature of the ring type tryout experimentally exploited in A, B and C regime

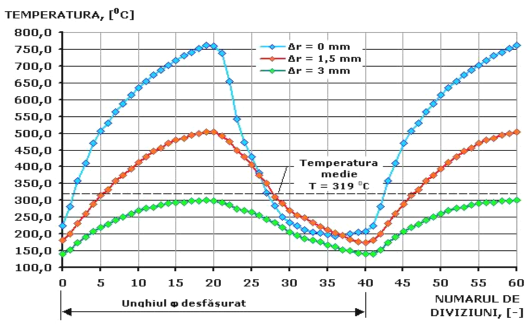
The experimental regimes	Superficial layer's depth Δr [mm]	Temperature variation in experiments [^{0}C]	
		Maximal	Minimal
Regime A	0	776.7	239.2
	1.5	620.2	231.2
	3	499.2	219.2
Regime B	0	767.4	195.2
	1.5	505.0	180.3
	3	348.3	152.1
Regime C	0	757.2	204.0
	1.5	505.0	180.3
	3	292.6	140.6



Figures 4 The cyclic temperature variations in points, at the surface and in the superficial layer (regime A)



Figures 5 The cyclic temperature variations in points, at the surface and in the superficial layer (regime B)



Figures 6 The cyclic temperature variations in points, at the surface and in the superficial layer (regime C)

Table 3 The number of thermal cycles and cyclical thermal solicitation regimes

Type	Number of thermal cycles		
	Regime A	Regime B	Regime C
55VMoCr12	$194 \cdot 10^3$	$181 \cdot 10^3$	$159 \cdot 10^3$
90VMoCr15	$175 \cdot 10^3$	$162 \cdot 10^3$	$148 \cdot 10^3$
OTA3	$245 \cdot 10^3$	$225 \cdot 10^3$	$195 \cdot 10^3$
65VMoCr 15	$186 \cdot 10^3$	$169 \cdot 10^3$	$152 \cdot 10^3$
FNS2	$218 \cdot 10^3$	$182 \cdot 10^3$	$173 \cdot 10^3$
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 separate for each set of tryouts formed of six rings, representing the 6 studied steel and cast iron marks, 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 visualizations.
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 Table 3.

4. CONCLUSIONS

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. 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.
- ✓ in regime A, the materials under study resisted longest at stress cycles, until the first thermal fatigue cracks appeared (loading regime); in 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 type of stress which gave the best results regarding stability to thermal fatigue – studied in stress regime C – is the OTA3 steel type;
- ✓ types 65VMoCr15, 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 behaviour was noticed at FNS2, which underwent to 173,000 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.

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. 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.
This research is a novelty scientifically for the fundamental and experimental research area upon the hot rolling rolls. 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.

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