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Increasing of rolling mill rolls durability in operation. Part I

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Abstract. By analyzing the situation in the industrial practice, was established that the structure obtained at the rolling mill rolls manufactured in the country according to classical technology does not ensure the necessary hardness and durability in operation.
The research carried out in operating conditions ensured the obtaining of structures that would give the rolls hardness as high as possible without diminishing the imposed toughness characteristics (resilience, elongation). From the variants experienced in operation, those with high technological and scientific value were selected, resulting that with the increase of resistance characteristics, the resilience did not decrease, and the exploitation durability doubled compared to the cylinders processed by classical technology.

Keywords: structure, exploitation durability, toughness, resilience, primary thermal treatment, secondary thermal treatment.

1. Introduction

The technological processes for rolling mill rolls manufacturing, as well as the quality of the materials used, know a great expansion, materializing through competition on the world market.
In the context of the market economy, to face the competition, many of the rolling mill rolls manufacturers had to permanently develop their research sectors, laboratories for rolls quality checking and create materials with superior characteristics and so an improved durability [1];[2].

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Rolling mill rolls, like many other machine parts in metallurgical aggregates, are subjected to complex and variable stresses with particularly pronounced thermal influences.
Our research on improving the technology of execution and heat treatment of rolling mill rolls is a national novelty. For this purpose, in order to highlight and clarify many problems in the field of rolls manufacturing technology, we used the scientific correlation between the action of stresses of all kinds in direct connection with operating conditions, the structure and composition of metallic materials used. This required the full use of known results from practice that only experience has allowed us to apply.
Thus, the work is part of the technical capitalization of improving the rolls manufacturing technologies made from local steel type 55VMoCr12 which was chosen and there is a concern from metallurgical companies and machine builders, having as purpose of increasing durability in operation.
The work done out on the basis of an economic contract with the Metallurgical Commercial Company from Hunedoara where the researches regarding the improvements brought to the technological processes of rolling mill rolls manufacturing were carried out, as well as at the Faculty of Engineering from Hunedoara where some aspects regarding the thermal resistance stage of hot rolling mill rolls have been finalized [3];[4].
Fig. 1 shows the overview of several types of rolling mill rolls.

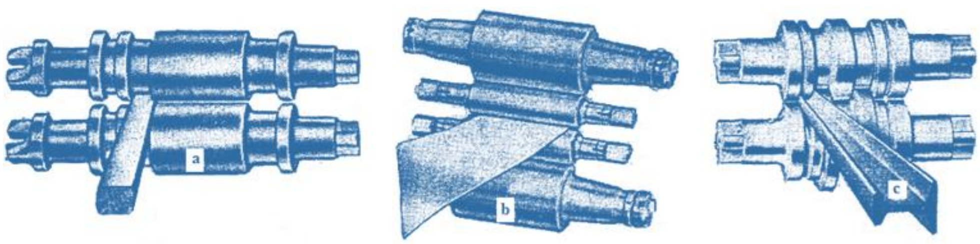


Fig. 1. Rolls for rolling mill: a - blooming; b - sheet metal, c - rails and beams.

Many aspects of the hot rolling thermal regime are still little studied, no effective methods are known to determine the evolution of the temperature in the mass of the rolls when operating with different regimes and their proper protection [5];[6].
Under the most favorable operating conditions, specific thermal fatigue cracks appear on the working surface of the rolling mill rolls, which limit their use during a rolling campaign, after which the cylinders are recalibrated to be used again.
Hot rolling rolls work in variable compound stresses conditions which are due to the rolling-plastic deformation processes of the metal and which are repeated at certain cyclic intervals [7].
The metallic material which deforms produces first of all an abrasive wear of the rolls to which is added the action of normal and tangential stresses, as well as of the stresses produced by the temperature variations [8] that have the highest values.

The compound stress state is the result of the simultaneous action of bending stresses, contact pressure, compression and tension, twisting and cyclic temperature variations [9].
Repeating heating and cooling at each rotation of the cylinders produces cyclic variations of temperature [10], both in the surface layers of the roll barrel and in the section of the rolling rolls, being generators of variable stresses, which together with mechanical stresses reach significant values that exceed in many cases the resistance limit of the material from which the rolls are made, causing specific cracks on their work surfaces [11].
The detailed analysis of the mentioned factors shows that the most pronounced thermal fatigue cracks appear in the roughing-mill stand rolls, where the influence of the thermal and mechanical stress factors is high, having a more pronounced character in the forged steel rolls.
Fig. 2 shows the gauges of a roll in the roughing-mill stand, on the surface of which the effects of thermal fatigue are observed [12].

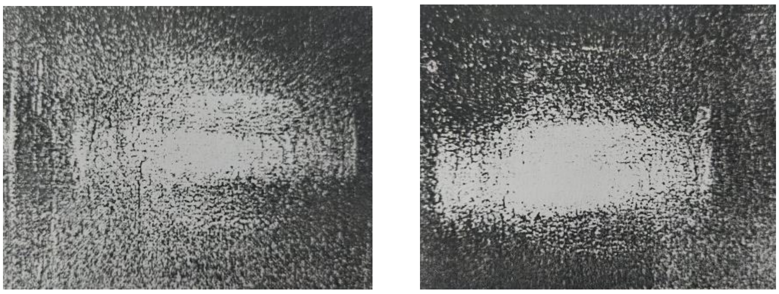


Fig. 2. The effects of thermal fatigue represented by cracks and fissures on the work surface.

2. The study of the problem in Romania

The state of research on the forged steel rolling mill rolls execution is in a rather incipient phase, and it is not possible until now to ensure the required structures and mechanical characteristics for operation.
At the Metallurgical Society from Hunedoara, tests were performed for the execution of forged steel rolls from 55VMoCr12, 85MoCrNi10 and 90VMoCr15 steel grades, with standardized chemical composition. The mechanical characteristics after secondary treatment must be within the limits provided by the norms.
Usually, the chemical analyzes are determined on samples taken at the casting of each batch, and the mechanical characteristics are established on heat treatment lots and batch. The hardness of the roll barrel is checked on 3 generators at 120° in three equidistant points on each generator, and on roll necks in two point at 180° radially symmetrical, for each roll [13].
The executed rolling mill rolls are delivered with a quality certificate regarding the verification of the chemical composition and mechanical characteristics to which are attached secondary heat treatment diagrams and the operating data sheet.

Thus the hardness of the roll barrel made of 55VMoCr12 steel was obtained only in the limits of 260-290HB, which represents a value well below the imposed limit. Forged steel rolls made of 85MoCrNi10, usually have a nominal diameter over ϕ700mm, and the hardness obtained according to the applied technologies did not exceed the limits of 280-320HB.

According to the classical technology, the execution of the rolls made of 90VMoCr15 steel grade was the most studied, at which, following the applied heat treatments, a uniform structure and a finer granulation were obtained, as well as better machinability.

Analyzing in detail the technology of forging and heat treatment of rolling mill rolls made from the mentioned steel grades, it can be concluded that it is not based on a vision of applied scientific research.

Thus, in the applied practice, the structure obtained by hot plastic deformation were no longer correlated, nor were removed the gases from the steel by heat treatment, leading to a harmless gas content in the roller material.

The improvement of the classical technology used until the application of our research is not anticipated, but we note that before the primary heat treatment the dehydrogenation heat treatment for hydrogen diffusion and the normalization for the finishing of the granulation were not applied. Also in the heat treatment technological process did not apply certain operations on the roll necks, in order to obtain lower hardness compared to the roll barrel. This difficulty caused the hardness in the roll neck section to be excessive, which led to damage by breaking them during the operation process [14].

As mentioned, rolling mill rolls must possess high operating qualities determined mainly by hardness, strength and stability at high temperatures. These qualities determine the resistance to sudden temperature variations during the rolling process.

The current quality requirements are best met by forged steel rolls, made of steel alloyed with chromium or in some cases with elements that form carbides (vanadium, molybdenum)[15].

After forging, the rolls are subjected to the primary heat treatment, which consists of the following phases:

- Normalization;
- Spheroidising annealing;
- Dehydrogenation heat treatment.

The temperatures established for the primary heat treatment were:

- Normalization, at 950°C with air cooling;
- Spheroidising annealing, at 820-600°C with furnace cooling;
- Dehydrogenation heat treatment, at 710°C with furnace cooling.

This treatment aimed the uniformization and finishing the granulation, carbides spheroidising, with ensuring a hardness that allows good machinability, dehydrogenation bringing the material to a lower gas content, avoiding the appearance of flake defects and segregation cracks, as well as ensuring better ultrasonic transparency.

The primary heat treatment was performed in furnaces with movable hearth, heated with methane gas, and the heating for normalization was performed at a speed of 50°C/hour so that when the furnace reaches the temperature corresponding to normalization, the entire load has the same temperature.
The secondary heat treatment depends on the quality of the steel and consists of oil quenching and high tempering, applied to the rolling rolls after the gauge reduction operation, and aims to obtain an improved structure throughout their mass at the required hardness level, as well as the mechanical properties required in operation.

3. Industrial experimentation

As the rolls are parts subjected to complex loads, it is necessary the strictly compliance of the manufacturing cycle starting with the elaboration and casting of the ingots until the final processing.
The paper presents the research and results obtained on rolling mill rolls by applying several variants of secondary heat treatment, treatment that gives the rolls superior characteristics, a much better operating behavior and a hardness comparable to those of import.
The 55VMoCr12 steel grade was chosen, and two rolls used for hot strips rolling were studied, having the following basic characteristics:

- Roll barrel diameter, *D*=ϕ550mm;
- The length of the roll barrel, *l*=1700mm
- Total length of the roll, *L*=2560mm

The chemical composition and the physico-mechanical characteristics of the two rolling mill rolls are found in tables 1 and 2.

Table 1.

Chemical composition, %									
C	Si	Mn	P	S	Mo	V	Cr	Ni	Cu
0.55-0.65	0.20-0.37	0.35-0.65	max. 0.04	max. 0.04	0.30-0.50	0.10-0.20	1.00-1.30	max. 0.3	max. 0.2

Table 2.

Mechanical characteristics										
Yield strength $R_{p0,2}$ [N/mm^2]		Tensile strength R_m [N/mm^2]		Elongation A [%]		Reduction in Area [%]		Resilience KCU [J/cm^2]		Hardness HB
L	T	L	T	L	T	L	T	L	T	
min. 450	min. 420	Min. 800	min. 760	9	6	30	15	30	20	240-285

L - values for longitudinal samples;
T - values for cross-sectional samples.

The elaboration of the steel from which the experimental rolls were obtained was made in the 50 t electric furnace, and the casting was done in ingots of 24 tons, from each ingot obtaining two rolling mill rolls.
After casting, the ingots were transported in a hot state to the forging section (temperature of at least 700-800°C in the lower part) and reheated to a deformation

temperature of 1180°C in movable hearth furnaces. Free forging was performed on the 1500KN press, the number of reheating being established depending on the complexity of the roll, the chemical composition of the steel, as well as the real conditions in the rolling mill section.

By forging the ingots at the 1500KN press, was ensured a ratio between the initial and the final area of the section of the ingot at least 3, this ensured by stretching and pressing.

After the forging operation, the final heat treatment was applied, following the objectives:

- uniformization and finishing of the granulation, so the correction of the structure obtained by plastic deformation;
- achieving better ultrasonic transparency;
- obtaining an optimal hardness for mechanical processing;
- elimination of steel gases through the mechanism of dehydrogenation treatment to bring the material to a harmless gas content to avoid the appearance of flakes and segregation cracks.

After the gauge reduction operation, the secondary heat treatment was applied and a suitable structure was obtained, which would give the steel the qualitative characteristics imposed by the industrial practice.

The initial technical documentation provided for the execution of these forged alloy steel rolls with a hardness of at least 58 Shore C (42 HRC or 400 HB) on a depth of 20 mm according to the execution drawing. Obtaining this hardness at a depth of 20 mm requires a surface hardening installation with a frequency of 5000Hz.

The rolls being intended for hot rolling, we consider that the application of the surface hardening process is not suitable, this being indicated only for the cold strip rolling mill rolls. Because the rolls intended for hot rolling are subjected to frequent shrinkage, the depth of the surface hardening layer on the mentioned depth disappears after the first turning.

Based on these considerations, we chose that the hot rolling rolls be made of 55VMoCr12 steel grade with a hardness of 245-285 HB, made at a sufficient depth, which includes all the turns during the operation campaign.

Following the research on the operating behavior of these rolls, a lower hardness was found than the imported cylinders, which is why we sought to obtain a higher hardness both by changing the heat treatment cycle and possibly changing the steel grade.

In order to choose the optimal solution, the high stresses to which the rolls are subjected were taken into account, as well as the requirement to obtain superior mechanical characteristics to satisfy the real operating conditions.

During the operation, no premature decommissioning due to ruptures or cracks, but only some wear, was reported, the manufacturing flow was intervened to improve the secondary heat treatment cyclogram. The advantage of this solution is that after the treatment a structure is obtained that ensures the resistance characteristics to the required values without diminishing the toughness characteristics. But, as a

disadvantage, the larger series of rolls cannot be treated in flow due to the lack of oil cooling tanks in the secondary treatment workshops.
Another solution is to choose a steel with a higher carbon content, alloyed with Cr, Mo and V, which will better meet the working conditions in operation. In the experiments performed, the first option was chosen as more economical. It was possible to obtain a fine and uniform austenitic granulation (score 6-10) after the forging operation, conditioned by the last heating from the forging.
After forging, the cylinders were cooled in direct air to 550°C, then moved to a heat treatment furnace for primary heat treatment at 860°C for softening annealing, followed by cooling in air by discharge from the hearth of the furnace up to 400°C to finish the structure obtained after forging. It continues with another heating to 700°C, in order to remove the flakes, after which a slow cooling is applied together with the furnace (Fig. 3).

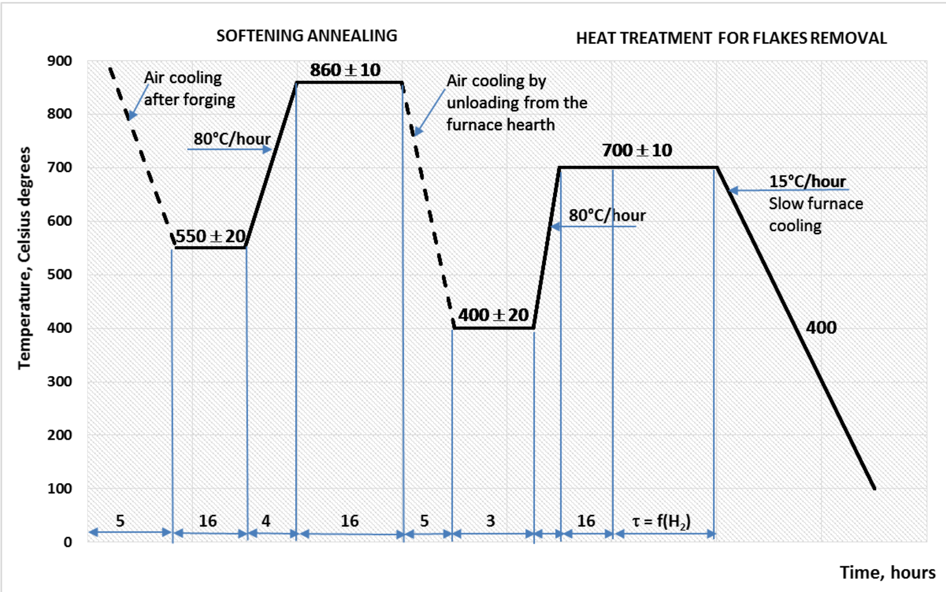


Fig. 3. Primary heat treatment cyclogram, applied after forging.

After the primary heat treatment, the forged experimental rolls were subjected to the gauge reduction operation with high processing addition, after which a secondary heat treatment was applied consisting of a quenching in air in the whole mass of the cylinders, followed by a high tempering (Fig. 4).

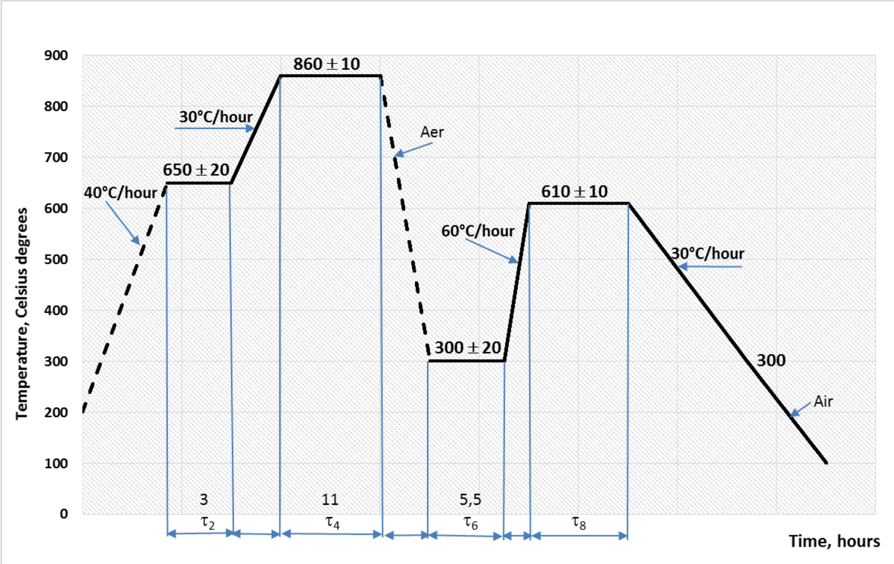


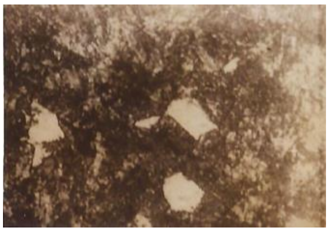
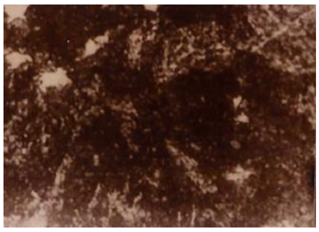
Fig. 4. Secondary heat treatment cyclogram, applied to rolls after gauge reduction

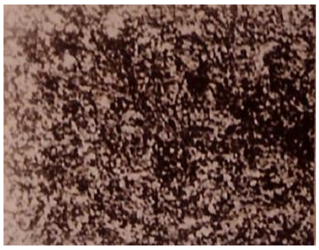
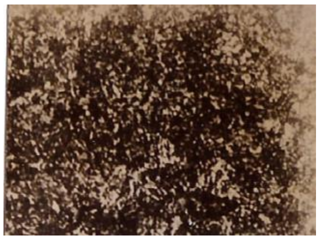
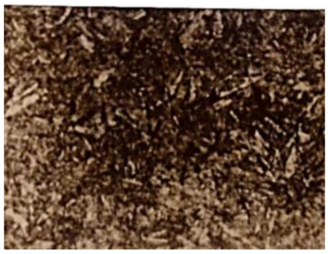
The values of the qualitative characteristics resulting on the rolls following the secondary treatment are included in the interval of those allowed by the technical documentation.

Given the requirements for increasing the hardness and strength characteristics, the research aimed to establish the optimal parameters of heat treatment, so that the structure meets these requirements.

Were experimented 7 variants of secondary heat treatment, whose qualitative results are given in table 3. Among the variants applied it is observed that the heating at 880°C is higher in order to obtain an austenite with a higher degree of alloy leading to obtaining a fine and evenly distributed bainitic structure (see structure from treatment 6-7). After quenching in oil at a temperature of 880°C, a double tempering at 570°C was applied, shown in Fig. 5, and it was found that with the increase of the resistance characteristics, the resilience did not decrease, observing a higher durability in operation.

Table 3. The value of the qualitative and structural parameters resulting from the research of rolls made from 55VMoCr12 steel grade.

No.	**Thermal treatment**	**Mechanical characteristics**						**Structure after treatment Scale: 500:1**
		Yield strength, $R_{p0.2}$ [N/mm^2]	Tensile strength, R_m [N/mm^2]	Elongation, A [%]	Reduction in Area [%]	Resilience, KCU [J/cm^2]	Hardness, HB	
1.	Quenching 860°C (air) Tempering 580°C	713	1089	12	32.7	37	321	
2.	Quenching 860°C (air) Tempering 550°C	662	1162	12	34.3	24	330	
3.	Quenching 860°C (oil) Tempering 560°C	660	1170	12	34.5	25	328	
4.	Quenching 860°C (oil) Tempering 610°C	816	1134	12	36.2	42	356	

No.	Thermal treatment	Mechanical characteristics						Structure after treatment Scale: 500:1
		Yield strength, $R_{p0.2}$ [N/mm^2]	Tensile strength, R_m [N/mm^2]	Elongation, A [%]	Reduction in Area [%]	Resilience, KCU [J/cm^2]	Hardness, HB	
5.	Quenching 860°C (oil) Double Tempering 600°C	815	1140	12	36.5	42	360	
6.	Quenching 880°C (oil) Double Tempering 570°C	943	1285	11	36.2	36	383	
7.	Quenching 880°C (oil) Double Tempering 580°C	891	1192	10	35.7	32	374	

From the experimented variants, it was sought to obtain a structure that would give the cylinders as much hardness as possible, without diminishing the toughness characteristics (resilience, elongation).

Therefore, the optimal variant for the secondary treatment is the cyclogram from Fig. 5, by which after hardening in oil at 880°C a double return to 570°C was applied, resulting that with the increase of the resistance characteristics, the resilience did not decrease and the durability in operation doubled, compared to the cylinders processed according to the classical technology.

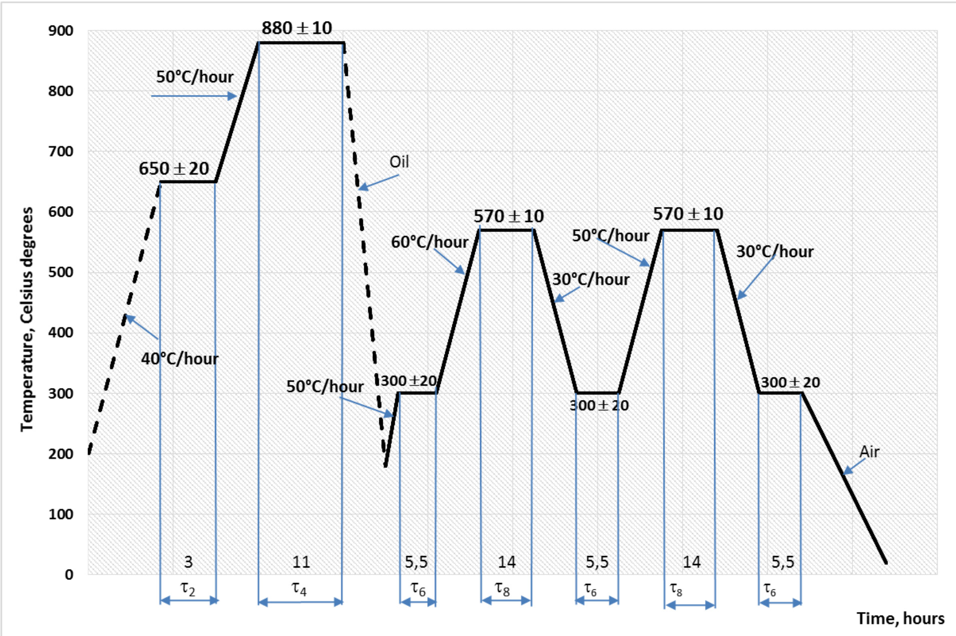


Fig. 5. The optimal variant for secondary thematic treatment

Conclusions

The experiments performed with forged alloy steel rolls, managed to ensure the properties required in operation, especially the resistance to thermal and mechanical shocks, making it possible to give up the import.
Also, the researches carried out in operating conditions aimed at obtaining structures that would give the rolling mill rolls as much hardness as possible without diminishing the toughness characteristics (resilience, elongation).
From the experienced variants, those with high technological and scientific value were selected, resulting that with the increase of resistance characteristics, the resilience did not decrease, and the durability in operation doubled compared to the rolls pressed according to the classical technology.

References

[1] Bataille C., Luc E., Bigerelle M., Deltombe R., Dubar M., *Rolls wear characterization in hot rolling process,* Tribology International, **100**, 2016, p. 328-337.

[2] Park J., Kim C., Lee S., *Evaluation of thermal fatigue properties of HSS roll materials,* Metal, 2003.

[3] Ilca I., Balazsi Şt., *Experimental research regarding improvement of quality characteristics and working life of forged rolls exploitation*, Contract de cercetare ştiinţifică Nr.10/1999-Etapa I.

[4] Ilca I., Balazsi Şt., *Experimental research regarding improvement of quality characteristics and working life of forged rolls exploitation*, Contract de cercetare ştiinţifică Nr.11/2000-Etapa 2.

[5] Achamyeleh T., Şahin Y., *Investigation of mechanical properties of ribbed reinforcement steel bars: a case study on ethiopian construction industry*, International Journal of Steel Structures, 2019, https://doi.org/10.1007/s13296-019-00236-0

[6] Daramola O.O., Adewuyi B.O. and Oladele I.O., *Effects of heat treatment on the mechanical properties of rolled medium carbon steel*, Journal of Minerals & Materials Characterization & Engineering, **9**, 8, 2010, p. 693-708.

[7] Benasciutti D., *On thermal stress and fatigue life evaluation in work rolls of hot rolling mill,* J Strain Analysis, **47**, 5, 2012, p. 297–312

[8] Spuzi S., Strafford K. N., Subramanian C., Savage G., *Wear of hot rolling mill rolls: an overview,* Journal WEAR, **176**, 2, 1994, p. 261 – 271

[9] Hu K., Zhu F., Chen J., Noda N.A., Han W., Sano Y., *Simulation of thermal stress and fatigue life prediction of high speed steel work roll during hot rolling considering the initial residual stress*, Metals, **9**, 2019, p. 966.

[10] Fedorciuc-Onisa, C., Farrugia, D., *Investigations into Roll Thermal Fatigue in Hot Rolling*, Int J Mater Form 1, 2008, p. 363–366, https://doi.org/10.1007/s12289-008-0070-8

[11] Bombača D., Kuglerb G., Markolib B., Terčeljb M, *Hot work roller surface layer degradation progress during thermal fatigue in the temperature range 500°C – 700°C,* International Journal of Fatigue, 104, 2017, p. 355–365.

[12] Ilca I., Kiss I., Miloştean D., *Study on the quality of Boron micro–alloyed steels destined to applications in the automotive sector*, International Conference on Applied Sciences, ICAS 2018, Banja Luca 10-11 May 2018, IOP Conf. Series: Materials Science and Engineering, **477**, 2019, 012003 (DOI:10.1088/1757-899X/477/1/012003).

[13] Ilca I., Miloştean D., *The deformability and thermal treatment for the low alloyed Romanian steel of high resistance*, Journal of Engineering Sciences and Innovation, **3**, 2, 2018, p. 141-154, AGIR Publishing House, ISSN-L2537 – 320X (on-line version).

[14] Ilca I., Miloştean D., *Improving the manufacturing technology of structural steels*, Journal of Engineering Sciences and Innovation, **4**, 3, 2019, p. 273-284, AGIR Publishing House, ISSN-L2537 – 320X (on-line version).

[15] Ilca Ioan, *Optimization of the thermal treatment technologies for the forged alloyed steel rolls*, Metalurgia internaţional, **4**, 2005, 46.