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THERMAL STRESS ANALYSIS USING FINITE ELEMENT METHOD IN AREA OF THE ROLLING MILLS ROLLS

Abstract:
The paper presents the analysis of thermal stress field distribution that occurs in the mill rolls, using finite element method. The finite elements method or the analysis with finite elements is based on the concept of building complicated object out of simpler ones, or dividing complicated objects into simpler ones, for which known schemes of calculation can be applied. The main idea in the method of finite element is to find the solution of a complicated problem by replacing in with a simpler one. The analysis of the thermal strains in rolling rolls, using finite elements method, has been carried out on Adamit-type rolls, cast of hypereutectoid steel and used in rolling profile I on the middle profile rolling train of Arcelor Mittal Hunedoara branch.
The industrial experimental data (rolling temperature, cooling water temperature, material characteristics etc.) are the basics for simulation program.

Keywords:
Rolling rolls, Simulation, Thermal Stress Analysis, Finite Element Method

INTRODUCTION

A particularly actual problem for the steel making companies is the low exploitation endurance of the rolling rolls, as they are the most stressed parts in the rolling train.
By taking into consideration thermal strains we could carry out a complete study, very close to the real conditions of rolling roll exploitation, as the thermal influences constitute one of the basic causes leading, even under favourable exploitation conditions, to thermal fatigue fissures, that reduce the use of rolls in rolling sessions [1].

THE EXPERIMENTAL ANALYSE

The analysis of the thermal strains in rolling rolls has been carried out on Adamit-type rolls, cast of hypereutectoid steel and used in rolling profile I on the middle profile rolling train of Arcelor Mittal Hunedoara branch.
The method of the finite element implies the generation of a discretizing lattice on the surfaces previously defined, taking into consideration the fact that all the knots and elements of the lattice are numbered [2], [3]. We mention that, on discretizing, we obtained a total number of 253613 elements and 49768 knots.

The plane discretizing of the rolling rolls and of the rolled profile are given in Figure 1 and Figure 2.

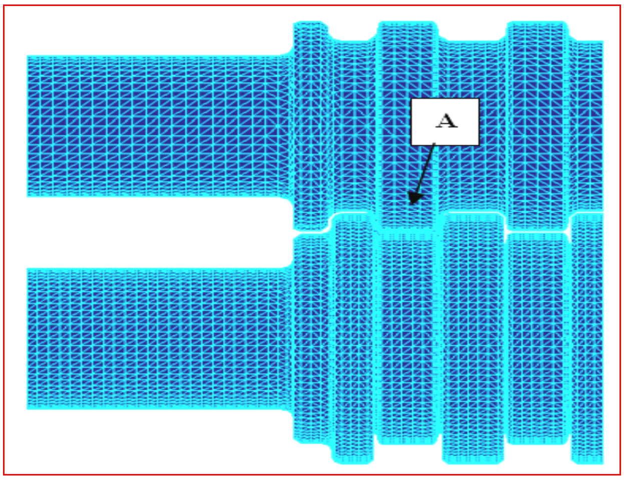

Fig. 1. Diagram of the plane modeling of the rolling rolls and the rolled profile I

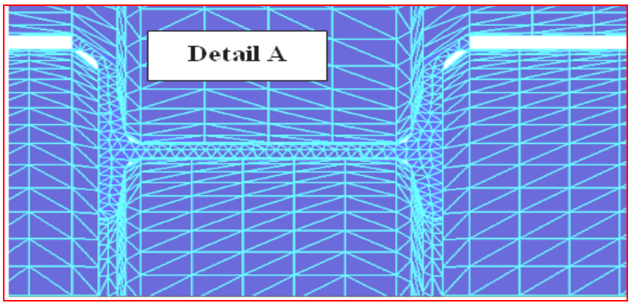

Fig. 2. Diagram of the plane modeling of the rolling rolls and the rolled profile I. Detail A

In order to determine the material thermal-physical properties, we took into account the fact that the steel that the rolling rolls are cast from is an Adamit-type, hypereutectoid steel, grade OT- A3, having the chemical structure given in Table 1. The steel to be rolled is an all purpose steel (OL 37), having the chemical structure given in Table 2 [4].

Table 1. The chemical structure of the Adamit-type, hypereutectoid steel

Steel grade	Chemical structure, %				
	C	Si	Mn	P_{max}	S_{max}
OTA3	1.8…2.0	0.6…0.8	0.7…0.9	0.04	0.02
	Cr	Ni_{max}	Mo	Cu_{max}	Ti_{max}
	1.0…1.2	1.6…2.0	0.3…0.5	0.2	0.06

Table 2. The chemical structure of the steel to be rolled

Steel grade	Chemical structure, [%]				
	C_{max}	Mn_{max}	Si_{max}	P_{max}	S_{max}
OL 37	0.20	0.80	0.07	0.06	0.06

The thermal-physical and material properties of the Adamit-type, hypereutectoid steel that the rolling rolls are cast from are [4]:

- *the coefficient of linear expansion:*

$$\alpha = 13 \cdot 10^{-6} \frac{1}{K};$$

- *thermal conductivity:*

$$\lambda = 31 \frac{W}{m \cdot K};$$

- *specific heat:*

$$c_p = 620 \frac{J}{kg \cdot K};$$

- *initial temperature:* $T_{initial} = 20^{o}C$.

The thermal-physical and material properties of the steel to be rolled, i.e. (OL37), respectively of profile I, are [4]:

- *the coefficient of linear expansion:*

$$\alpha_{100^{o}C} = 12{,}2 \cdot 10^{-6}\, grdC^{-1}; \alpha_{700^{o}C} = 14{,}9 \cdot 10^{-6}\, grdC^{-1};$$

- *thermal conductivity:*

$$\lambda_{800^{\circ}C} = 25 \frac{W}{m \cdot K} \qquad \lambda_{20^{\circ}C} = 50 \frac{W}{m \cdot K};$$

- *specific heat:*

$$c_{p\,20^{\circ}C} = 452 \frac{J}{kg \cdot K}; c_{p\,600^{\circ}C} = 753{,}3 \frac{J}{kg \cdot K}; c_{p\,800^{\circ}C} = 933{,}3 \frac{J}{kg \cdot K}$$

- *initial (rolling) temperature:* $T_{rolling} = 800^{o}C$.

DETERMINATION OF THE STRAIN STATE IN CASE OF APPLYING THE COOLING WATER ON TWO SURFACES

In case of calculating the thermal strains at 800°C, the rolling rolls being cooled on two surfaces, we took into consideration the fact that the strains in the neck areas are not relevant because movements were null here ("expansion blocked"), as the bearing clearance was ignored.

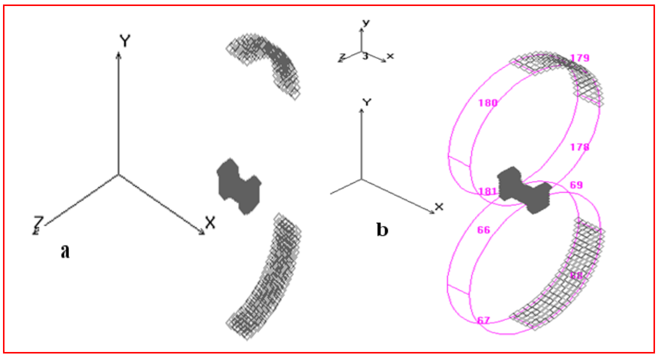

Fig. 3. The rolling roll cooling diagram, without displaying the surfaces the cooling water is applied on (position a) and displaying them (surfaces 68 and 179) (position b)

The diagram of the water cooled surfaces with respect to the position of the rolled section is given in figure 3.

In order to draw the diagrams corresponding to the thermal strains in the knots placed on the critical rolling areas of the roll circumference, it is necessary to place the knots on the circumference of the groove pass. In order to draw the diagrams corresponding to the thermal strains in the knots placed on the critical rolling areas of the roll circumference, it is necessary to place the knots on the circumference of the groove pass.

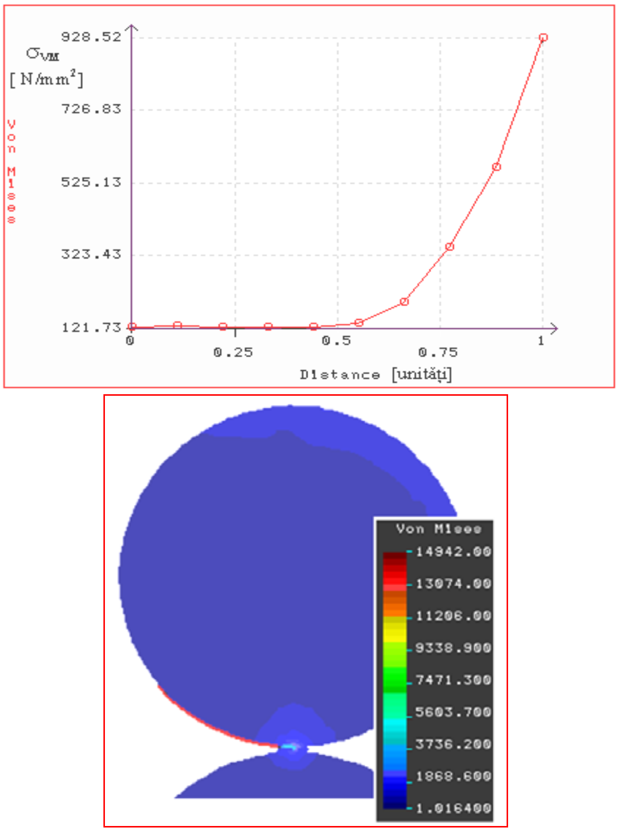

Fig.4. Variation of the Sigma Von Mises strains

In Figure 4 we gave the ensemble of the roll cross-section, as well as the magnitudes of the Von Mises strains for the following knots (schematically pointed out on the surface of the upper roll): 35215, 35218, 35221, 35224, 35227, 35230, 35233, 35236, 35239 and 35242. In the plan given in fig.3, one can notice an increase in the thermal strains towards the rolling area (the profile). Thus, for knot 35215 Von Mises strain is 121.73 N/mm² and for knot 35242, of 928.52 N/mm². The distance between the first and the last knot under study represents 167.88 mm (in the graph given in the figure, it is considered to be equal to the unit).

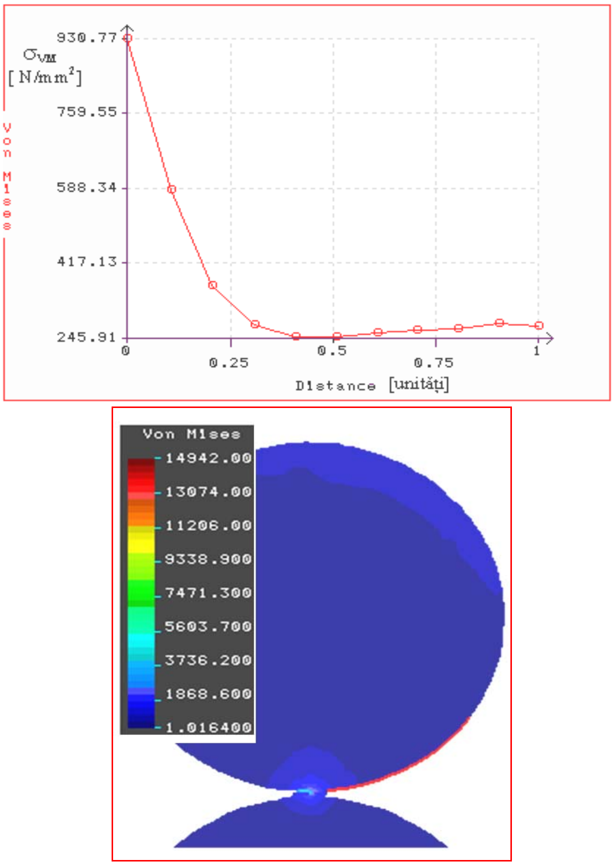

Fig. 5. The variation of Sigma Von Mises strains

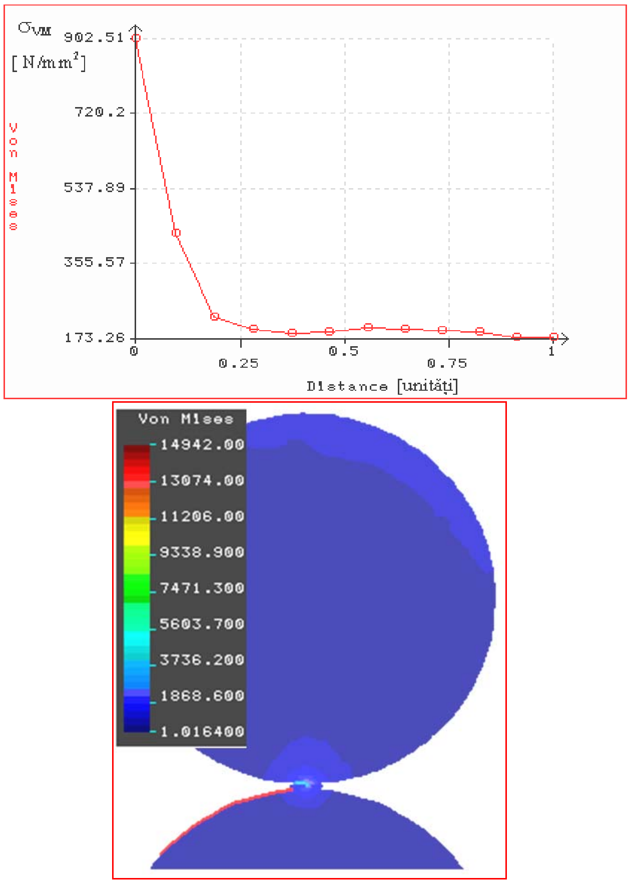

Fig. 6. The variation of Sigma

In Figure 5 we gave the ensemble of the roll cross section, as well as the magnitudes of the Von Mises strains for the following knots (schematically pointed out on the surface of the upper roll): 35126, 35129, 35132, 35135, 35138, 35141, 35144, 35147, 35150, 35153 and 35156. The diagram shows a decrease in the thermal strains away from the rolling area, knot 35126 having a Von Mises strain of 930.77N/mm² and knot 35156 of about 246 N/mm². In this case, the calculated length is 185.1947mm.

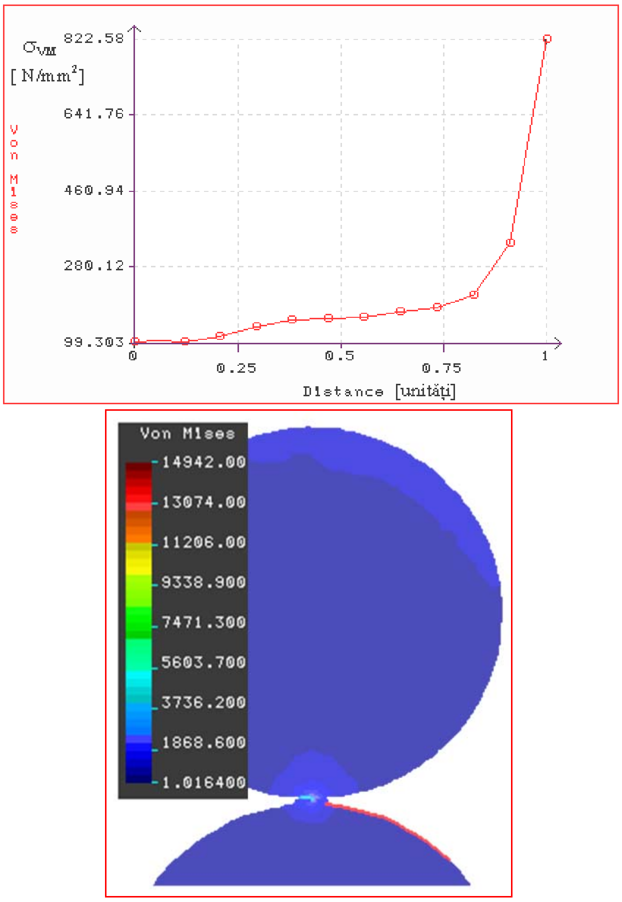

Fig. 7. The variation of Sigma Von Mises strains

Similarly, in Figure 6 we gave the ensemble of the roll cross section, as well as the magnitudes of the Von Mises strains for the following knots (schematically pointed out on the surface of the upper roll): 4277, 4281, 4285, 4289, 4293, 4297, 4301, 4305, 4309, 4313, 4317 and 4321. In the plan given in Figure 6 one can notice a decrease in the thermal strain away from the rolling area. Thus, for knot 4277 Von Mises strain is of 902,51N/mm² and for knot 4321 of 173.26N/mm² (in this case, the calculated length is 185.1947 mm). In Figure 7 we gave the ensemble of the roll cross section, as well as the magnitudes of the Von Mises strains for the following knots (schematically pointed out on the surface of the upper roll): 4423, 4427, 4431, 4435, 4439, 4443, 4447, 4451, 4455, 4459, 4463 and 4467. Figure 7 shows that for knot 4467 Von Mises strain is of 822.58 N/mm² and for knot 4423 of 99.203 N/mm² (the calculated length is 185.1947 mm).

CONCLUSION

As a result of simulating the rolling process by means of the finite element method in view of quantitatively and qualitatively determining thermal strains, we came to the following conclusions:

- *thermal strains are the basic cause of fissuring the rolling surface of rolls as a result of thermal fatigue, caused by the high values in the areas neighboring the contact area with the incandescent semi-finished part; the graphs show that the values of the thermal strains in the area under consideration rank within 121,73 and 930.77 N/mm² for the upper roll and 99.303 and 902.51 N/mm² for the lower roll;*
- *thermal strains have significantly higher values as compared to the mechanical ones and act at relatively short intervals of time (within fractions of a second);*
- *the rolling rolls break during the rolling process because of thermal fatigue;*
- *a most precise knowledge of the character of the strains generated by the complex stresses the hot rolling rolls undergo, allows the determination of the duration in exploitation under safe conditions, by their comparison to certain limit values imposed from the very beginning;*
- *strains in the rolling rolls have a cyclical character and the strain state is mainly the result of the action of the fields of symmetrical and asymmetrical temperatures that cause thermal fatigue on their surface and superficial layer.*

Engineering is concerned with the design of a solution to a practical problem. A scientist may ask why a problem arises, and proceed to research the answer to the question or actually solve the problem in his first try, perhaps creating a mathematical model of his observations. By contrast, engineers want to know how to solve a problem, and how to implement that solution. In other words, scientists attempt to explain phenomena, *whereas engineers use any available knowledge, including that produced by science, to construct solutions to problems.*

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 the exploitation. The proposal approaches the issue of quality assurance of the rolling mills rolls, from the viewpoint of the quality of materials, which feature can cause duration and safety in exploitation.

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