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STRESS/STRAIN ANALYSIS AT THE WHEEL - RAIL CONTACT UNDER THE INFLUENCE OF THERMO-MECHANICAL LOADS

BY

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Abstract. Cracking of wheels and railway tracks under thermal influence is investigated using a numerical approach. In this paper we present the results of the finite element analysis (FEM) of the interaction between the wheel and the railway track under the influence of thermo-mechanical loads. Determining the distribution of stresses and pressures is important for determining the life time and preventing cracks of the components in contact. The expected life time foreseen by simulation is in good concordance with the experimental results find in literature.

Keywords: Finite Elements Method; railways; wheel-rail; thermo-mechanical loads.

1. Introduction

The evolution and progress of human society cannot be achieved without movement, without transport. All life is movement, which has been synthesized in the Latin expression “via vita”. From the economic, social,

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political, informational, commercial, cultural, administrative, strategic, technical and scientific point of view, communication and transport links facilitate the connections between people, the economic exchanges between localities, regions and countries, ensuring the progress and development of all branches of activities. A safe, fast and comfortable transport system is railway transport. The technical structure of the vehicle-rail system consists of a fixed subsystem, which is the path, and a mobile subsystem, which is the rolling stock.

As long as the rolling stock is in stand-by, studying the interaction between the two subsystems to determine the state of effort, deformation and displacement can be undertaken using static balance-specific relationships. Any movement of the vehicle on a support with inherent defects (bumps, misalignments, variations in stiffness, etc.) moves the masses of the entire oscillating system in motion, establishing new interaction relations between the elements of the system, which can only be studied using methods of the dynamic balance. The connection and interdependence between the two subsystems, the vehicle and the track, is achieved at the wheel - rail contact. At this level, the vehicle develops inertial forces during the movement, the importance of which increases in once with the velocity. At present, in most cases, bogies made up of the bogie mass, elastic and damping elements, interposed between the box and the axle, the latter having the role of consuming kinetic energy and delaying the action of the forces at the wheel-rail contact.

Thermal influence over cracks in wheels and railways tracks is studied using numerical simulation. This paper presents the analysis with finite elements of the wheel-railways tracks interaction under thermal and mechanical loadings. In order to determine the lifetime and avoid the apparition of eventually cracks, the distribution of stresses and strains must be known. The simulation gave results in good concordance with experimental ones found in literature.

2. The Finite Element Method

Considering the trends of increased traffic speeds, increasing axle loads, but also decreasing waste material from wheel mounting rail respectively due to the phenomena of wear and tear, wear, fracture appearance of wave wheel and rail, it is required knowledge of the distribution of stresses and strains at the wheel-rail contact. This can be obtained either by finite elements method (FEM) (Crețu, 2009; Maksay, 2008; Faur, 2002).

FEM Procedure follows the steps: wheel/rail assembly model; the choice of model material; support conditions; conditions of wheel/rail contact; problem solving; interpretation of data. The following input data were employed: cross-sectional contact 0.28; wheel load of 110 kN; wheel profile S78; rail inclination 1/20; rail profile UIC60; track width 1435 mm; the distance between the inner faces of the two wheels 1360 mm; wheel diameter 760 mm;

lateral displacement of the mounted axle 0 mm; attack angle 0°. The CAD model was developed in the Autocad Inventor software 2019 (Hansen, 2019) and is shown below in Fig. 1.

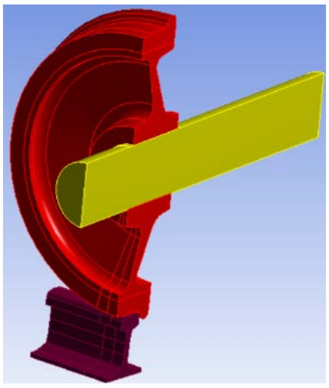

Fig. 1 – 3D model.

The mechanical properties of the material are presented in Table 1.

Table 1
Mechanical Characteristics of Materials Used in FEM Simulations

Steel	ρ, [kg/m^3]	σ_a, [MPa]	σ_r, [MPa]	E, [GPa]	υ
R7T (wheel)	7850	390	870	210	0.3
A2 (Axle)	7850	350	620	210	0.3
900A (rail)	7850	594	905	200	0.304

The elastic-plastic model employed for axle, rail and wheel was adopted from experimental data and is presented in Fig. 2. The elastic-plastic model of the wheel material function on temperature is shown in Fig. 3.

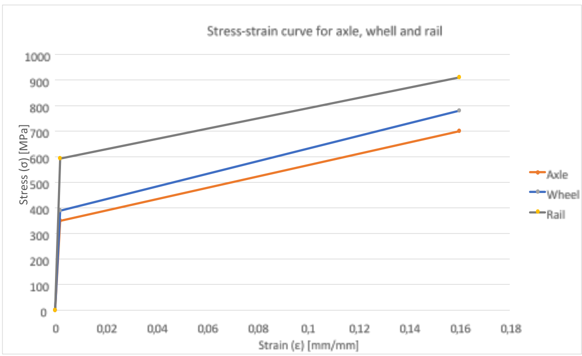

Fig. 2 – The elastic-plastic model adopted for axle, rail and wheel.

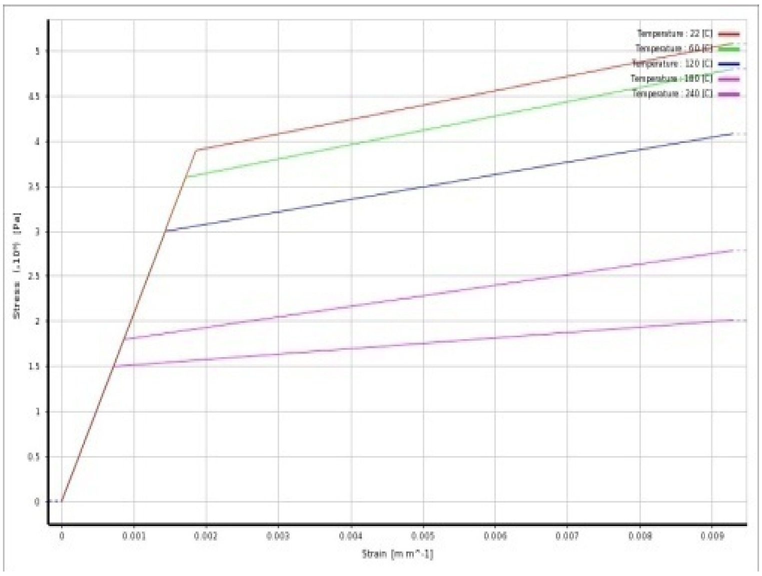

Fig. 3 – The elastic-plastic model of the wheel material *vs.* temperature.

The geometry was transferred into CAE software and discretized with 8-node *elem185* elements and is shown in Fig. 4. The contact area between wheel and rail was meshed with elements *conta174* on the surface of the wheel and elements *targe170* on the track surface. The model contains *190572 nodes* and *204846 items* for the global model. A vertical force of 50 kN is applied to half of the geometry, the rail is secured to the rail's foot to prevent movements. The effects of wheel rotation and lateral forces are neglected, Fig. 5.

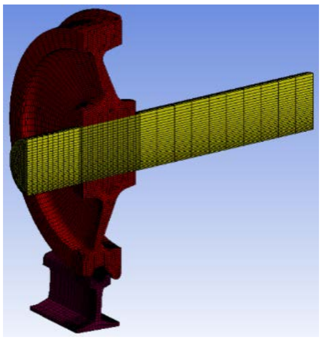

Fig. 4 – Meshing model.

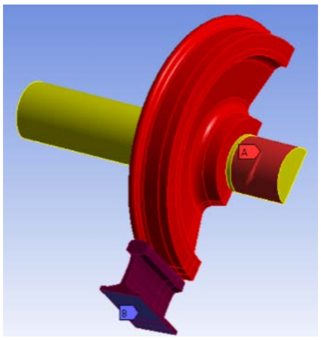

Fig. 5 – Supporting conditions.

The proposed FEM model represents a realistic modeling for axle - wheel - rail load transfer. Friction coefficients (Bărbînță, 2010) and thermal variation were also used, Table 2 and Table 3.

Table 2
Friction Coefficients Used in FEM Scenarios

μ	0	0.03	0.05	0.07	0.1	0.12	0.15	0.18	0.2	0.25
	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	

Table 3
Temperature Variation Used in FEM Scenarios

C°	22	60	120	180	240

3. Results Processing

In order to emphasize how the maximum stress distribution is influenced by friction, results were obtained considering that the value of friction coefficients along the x and y axes are given in Table 2 for the interaction between a *S78 profile wheel and a UIC60 rail for 1/20 rail tilt*, according to the elastic - plastic pattern (Fig. 6). Fig. 6 shows that the influence of friction on the stress distribution is increasing, the maximum stress being approximately 572 MPa for friction coefficients higher than 0.1. Friction coefficient for simulation was considered μ = 0.25.

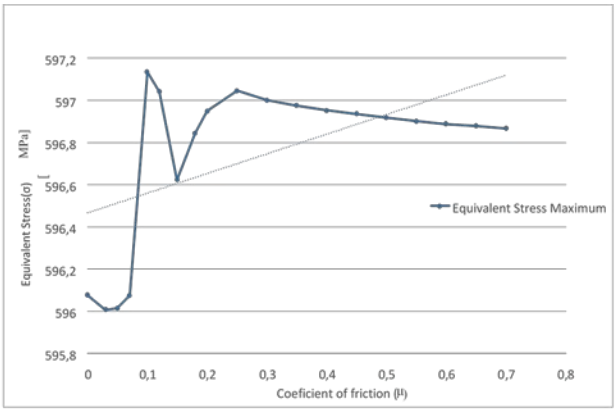

Fig. 6 – Maximum Von-Mises tension versus friction coefficient.

The maximum stress inspected on the global model is 597 MPa for a 2.98 mm deep wheel inside the running surface and 462.72 MPa for the track to the maximum stress at a depth of 3.2 mm inside the track running surface, resulting in Figs. 7-9. The maximum wheel stress is for the proportional limit, thus supporting plastic deformation.

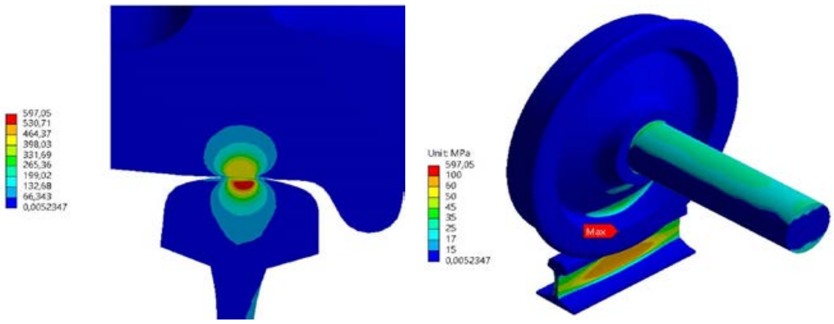

Fig. 7 – Stress distribution at wheel contact, g*lobal model*.

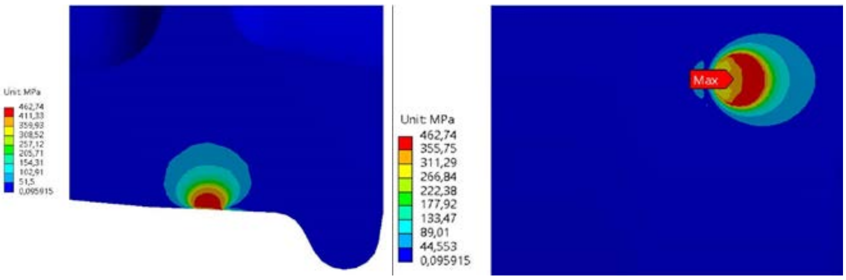

Fig. 8 – Stress distribution at wheel contact, *wheel*.

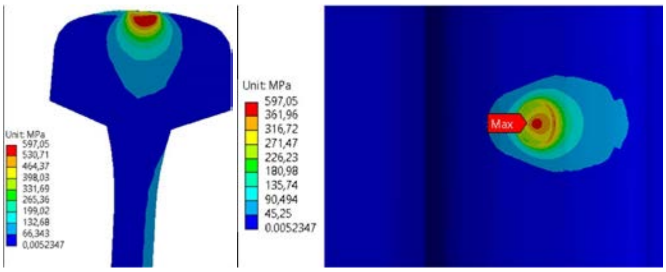

Fig. 9 – Stress distribution at wheel contact, *rail*.

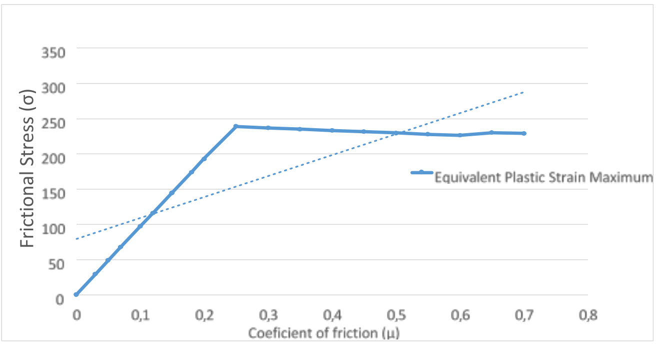

Fig. 10 – Distribution of contact stress function of friction coefficient.

Specific elastic deformations are presented in Figs.11-13.

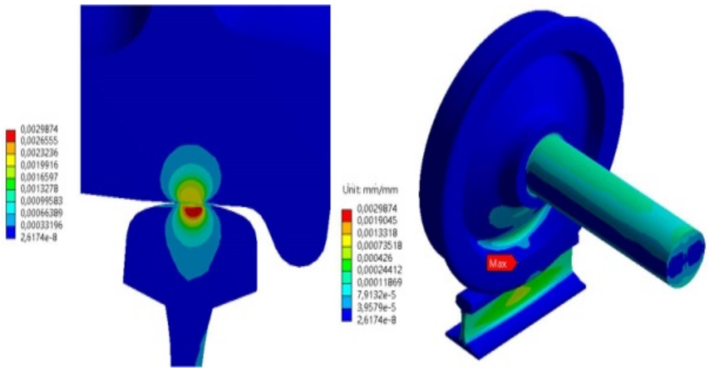

Fig. 11 – Distribution of elastic - specific deformations, *global model*.

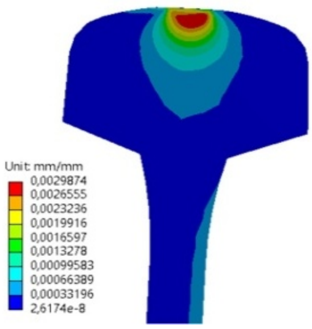

Fig. 12 – Distribution of specific deformations at wheel contact, *rail*.

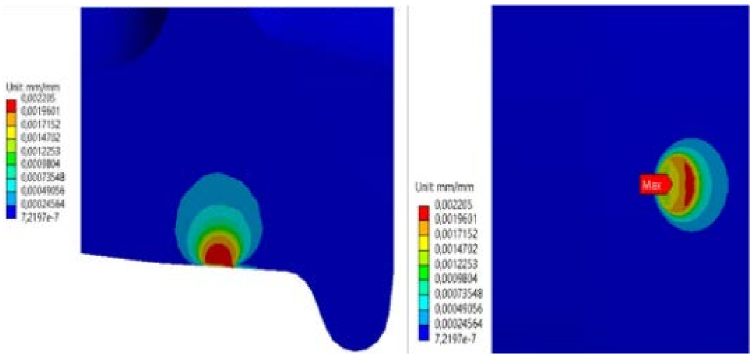

Fig. 13 – Distribution of specific deformations at wheel contact, *wheel*.

Specific plastic deformations are 4% calculated at a node, similarly, the values of the nodes in the vicinity of the concentrator are 1.2% and 1.3% for the wheel and 1% calculated at a node, similarly, the values of the nodes in the proximity of the concentrator being 0.6% and 0.5% for the rail, Fig. 14.

Looking at the distribution of the specific plastic deformations of the wheel and rail shown in Fig. 13, we can visualize the fracture due to cyclic loads, exactly in the area indicated in Fig. 14. The pressure distribution on the ellipse area is shown in Fig. 15.

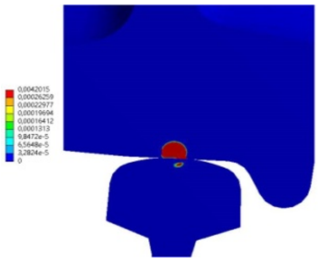

Fig. 14 – Distributions of specific plastic deformations, *global model*.

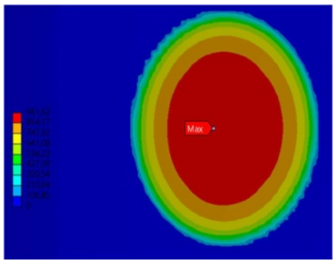

Fig. 15 – Pressure distribution on ellipse area, elastic model for μ = 0.25.

To highlight how the pressure distribution is influenced by friction, results were obtained considering that the value of the coefficient of friction along the x and y axes having the values of 0 - 0.7 for the interaction between a S78 profile wheel and a UIC60 rail for a rail tilt 1/20, according to the elastic - plastic model, Fig. 16.

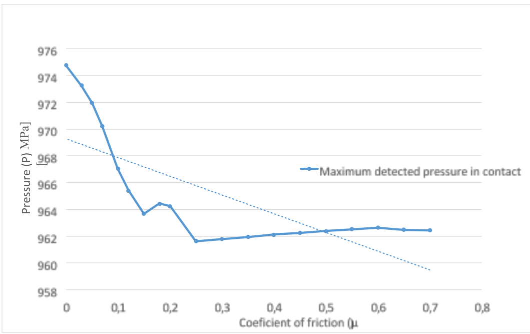

Fig. 16 – Distribution of 3D pressures, *vs*. friction coefficients.

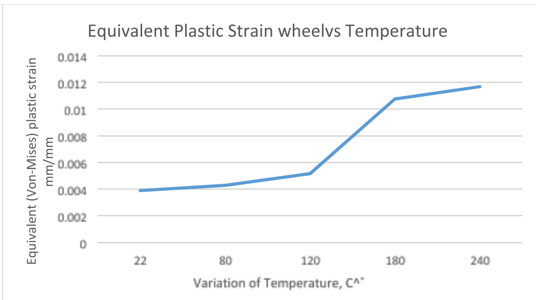

Fig. 17 – Distribution of specific maximum plastic deformations *vs.* temperature.

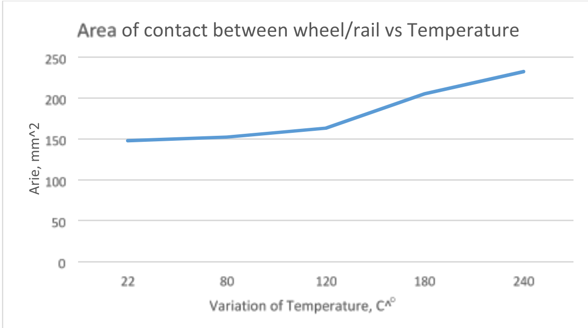

Fig. 18 – Contact area, the elastic - plastic model, *vs.* temperature.

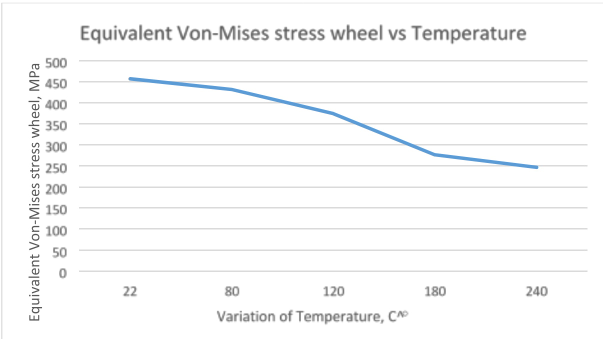

Fig. 19 – Von-Mises stress distribution depending *vs.* temperature.

4. Conclusions

Using a finite elements model of elastic-plastic body, a very rapid FEM model was obtained to solve the distribution of pressures and stresses at the concentric contact wheel-rail, for real contact surfaces, a preliminary model absolutely necessary for any study which requires analysis of the stress state and gradient pressures to such loadings for different situations of this interaction, modifying only the input data, the geometry, the mechanical and physical properties of the material.

The presence of friction forces on the contact area causes the effects:

- Asymmetric distribution of Von-Mises tensions;
- Increasing the maximum tension value Von-Mises;
- Locating the maximum value at lower depths.

The presence of temperature variations causes the effects:

- Increasing the contact area;
- Increasing the maximum value of Von-Mises specific plastic deformations;
- Locating maximum stresses at lower depths.

The increase in the relative value of the Von-Mises equivalent stress, the increase in specific plastic deformations, and the proximity to the maximum point contact surface have a negative effect on the durability of the wheel and rail fatigue operating under a rolling contact stress. These effects are pronounced as the friction coefficient gets higher.

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ANALIZA TENSIUNILOR ȘI DEFORMAȚIILOR LA INTERFAȚA ROATĂ-ȘINĂ SUB INFLUENȚA SARCINILOR TERMO-MECANICE

(Rezumat)

Un rol important în ceea ce privește cedarea, uzura și oboseala de contact, al elementelor componente la interfața roată-șină îl au: aria de contact, localizarea ariei de contact, starea de tensiuni și gradientul de presiuni, acestea fiind mai pregnante atunci când sunt influențate de sarcini termo-mecanice ridicate. În această lucrare prezentăm rezultatele analizei cu element finit (AEF), a interacțiunii contactului dintre roată-șină sub influența sarcinilor termo-mecanice. Determinarea distribuției de tensiuni și presiuni este importantă pentru determinarea duratei de viață și prevenirea fisurilor în componentele ce se află în contact. Rezultatele primite prin AEF sunt în concordanță cu rezultatele experimentale găsite în literatura de specialitate.