

Analysis of the distribution of temperature fields in the braked railway wheel

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Abstract. The article deals with detection of reduced stress in a braked railway wheel, based on thermal transient analysis on virtual models, which influence the characteristics of the railway wheels. Structural analysis was performed by means of the ANSYS Multiphysics program system package. Thermal transient analysis deals with detection of temperature fields which are a result of braking by brake block. The applied heat flux represents the heat generated by friction of brake block. It is applied to a quarter model of the wheel to speed up the calculation. This analysis simulates two braking processes with subsequent cooling. Distribution of the equivalent stress was detected in the railway wheel cross section, at selected points. The input parameters were taken from the thermal transient analysis. These equivalent stresses result from thermal load.

Keywords: railway wheel, brake block, structural analysis

1 Introduction

The brake system of railway vehicles is an important subsystem in terms of driving safety. Investigated issue is process of non-stationary temperature fields spreading, generated by the braking railway vehicles. The thermal load on the wheels has a significant rate on the influences due braking by the brakes, that lead to wear - modification and damage of the wheel tread [5, 15, 21]. In the braking process we have to take into account the fact, that the wheel is a brake block not only overheated at the point of their contact but also loaded with normal and tangential stress, which is the source and the necessary precondition for the braking process creation [7, 14]. With regard to the braking design and the braking mechanism, we include braking brakes between the adhesive brakes because the braking effect of the vehicle itself with respect to the track is realized by contacting the wheel and the rail via the contact patch [12, 18].

Researches must pay attention to studying the effects of thermal and mechanical loading wheels of railway vehicles of reasons: the operation of vehicles, protection of life and health of the traveling public, reliable transport material and minimizing the negative effects of rail traffic on the environment [10, 25].

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Article deals with the detection of residual stress in a braked railway wheel based on thermal transient analysis. Railway wheel is loaded by heat flux, which is applied on the contact surface. This topic is discussed in more detail in mentioned literature and references [1-4, 2, 3, 4, 6, 11, 19, 22].

2 Residual stresses

In design and computational practice, a material is usually considered as homogeneous isotropic continuum [9].

The deformation of bodies and stress occurrence happens mainly due to [17, 23]:

1. Mutual power action of bodies.
2. Action of field of temperature:
 - homogenous (tension appears when thermal dilatation of body is restrained),
 - non - homogenous (tension appears even if thermal dilatation of body is free).

If the plasticity condition is not satisfied, active tensions occur in elastic area and after removing of causes of their formation it completely disappear.

If formation of elastic plastic state arises in any point of a body, then after removing of formation causes (power, distortive and thermal), some residual stresses stay in a body [13, 20, 24].

Certain residual state of stress remains almost always in structural materials due to their production technology.

Residual stresses can be:

1. Helpful – e.g. peening is introduced compressive stresses in the surface layer, leading to prolongation of lifetime.
2. Harmful – cracking, corrosion stress, reduce fatigue limit or brittle fracture resistance (especially negative effect on tensile residual stresses).

High tensile stresses, induced, for example in the area of welds cools and phase transformations, may cause rupture even without additional external forces [8].

3 ANSYS program package

The program ANSYS (Fig. 1) uses the finite element method. Modeling of the finite element method belongs to the group of numerical methods. This method develops due to the constant increase in computing power. Its core is the discretization of bodies on the files of finite elements. These elements form analogue after parts field that can be mathematically written [16].

The ANSYS program is generally nonlinear, multiphysics program including structural and thermodynamic analysis, analysis of flow continuum, analysis electrostatic and electromagnetic fields, and acoustic analysis. All these analyzes can be performed individually, but thanks ANSYS multiphysics conceived program can also be included in one common analysis. [10]. The ANSYS program allows you to not only check calculations, but also enables optimization and sensitivity analysis due to parameterized computational models, as well as the calculations of reliability.

ANSYS Mechanical product is intended to simulate the structural and thermodynamic tasks. The program includes the complete set of linear and nonlinear simulation with using linear and non-linear elements, material models, and contact non-linear algorithms.

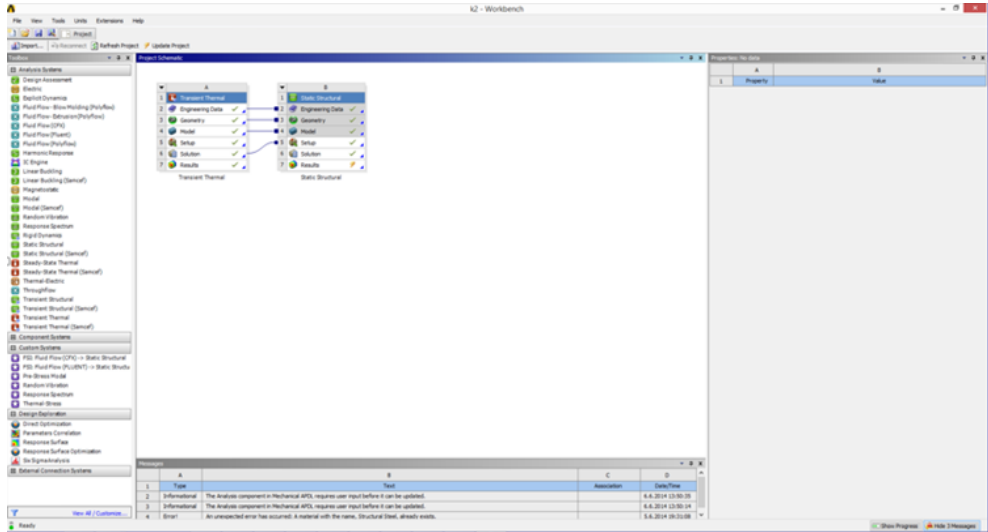


Fig. 1. ANSYS Workbench program system environment

4 Transient thermal analysis in ANSYS program

The problem simulates heating of the railway wheel tread. The railway wheel is braked by the brake block. The heat generated by the brake pad friction represents a heat flow of 32 kW (cast iron block) and 38 kW (composite block). This analysis simulates two braking for 100 seconds when the heat flow is applied to the wheel tread. Railway wheel cools for 300 seconds; after the first braking and 1000 seconds after the second braking. The value of heat flux is then zero. The composite brake block has a worse heat dissipation than cast iron and therefore heats the wheel's surface more heavily. The applied heat flux in the composite block is greater than that of the cast iron block.

A quarter model of railway wheel was created using CATIA program and imported into ANSYS program.

4.1 The definition of material properties

Railway wheel is made of steel DIN 40Mn4. The thermal properties used in the simulation are shown in Tab 1.

Table 1. Thermal properties of materials

Properties	Railway wheel	Air
Density ρ [kg.m ⁻³]	7850	1.170
Heat capacity C_p [J.kg ⁻¹ .K ⁻¹]	486	1100
Thermal conductivity k [W.m ⁻¹ .K ⁻¹]	52	0.026
Emissivity – wheel tread[-]	0.20	-
Emissivity – other surfaces	0.80	
Dynamic viscosity [Pa.s]	-	1.8.10 ⁻⁵

4.2 Definition of boundary conditions

A quarter model was used because of the acceleration calculation. The symmetry has been applied to the model.

The values of the heat flux (power) 32 kW (cast iron block) and 38 kW (composite block), which is applied to the wheel tread (Fig. 3) are shown in table 2. Dependence heat flux to time is shown in Fig. 2. Simulation did not involve wheel rotation or thermal expansion of the wheel.

Table 2. Dependence heat flux to time

Step	Time [s]	Heat flux [W]
1	0	0
1	10	32000 (38000)
2	100	32000 (38000)
3	101	0
4	400	0
5	410	32000 (38000)
6	500	32000 (38000)
7	501	0
8	1500	0

Dependence heat flux to time

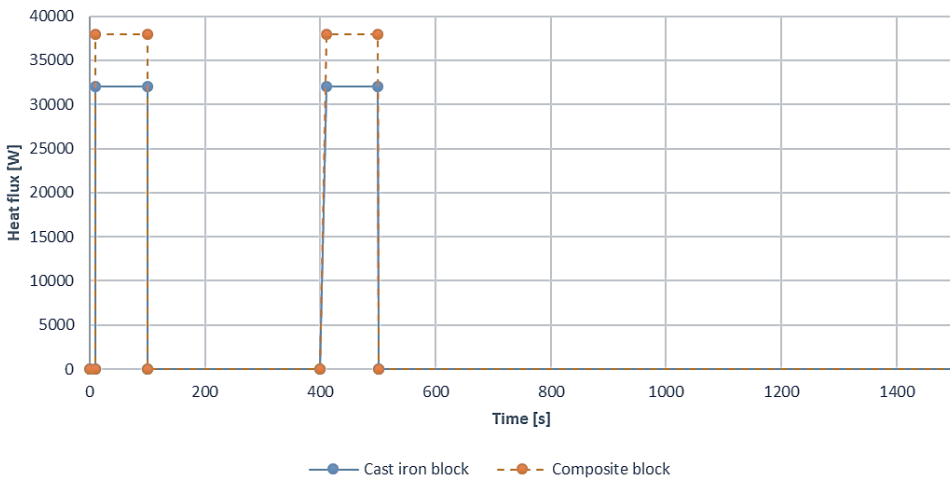


Fig. 2. Dependence of a heat flux to time

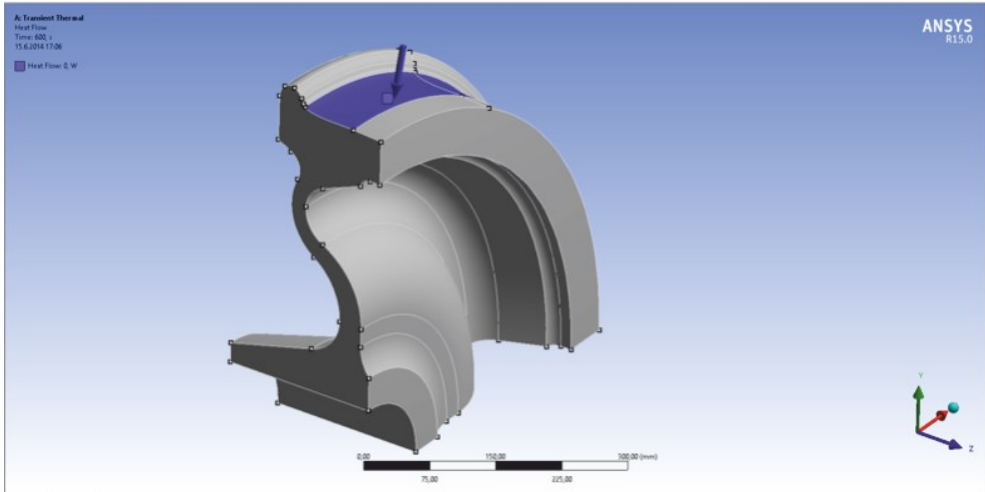


Fig. 3. Heat flux applied to the tread of the rail wheel

Reference ambient temperature was set to 22°C.
Thermal radiation was set to all areas of railway wheel.
Six degrees of freedom were taken to the railway wheel. (Fig. 4).

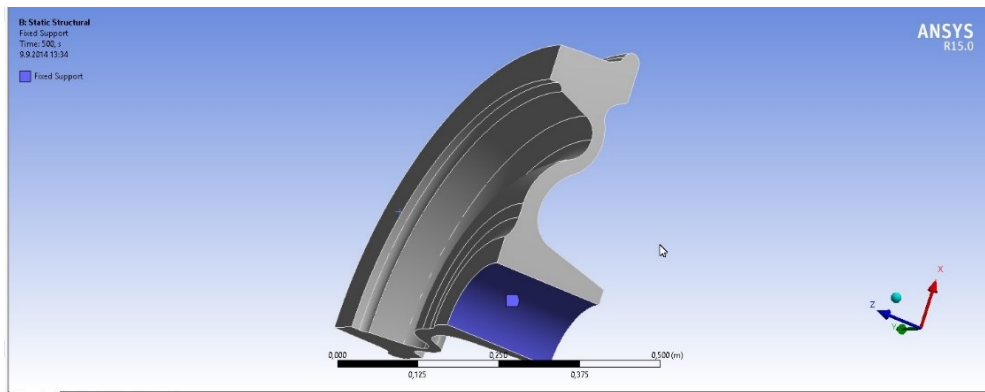


Fig. 4. Applied boundary conditions

Finite element mesh (Fig. 5) was created according to the dimensional parameters with the following parameters:

- element size: 10 mm,
- element type: SOLID 90,
- number of elements: 5075,
- number of nodal elements: 26156.

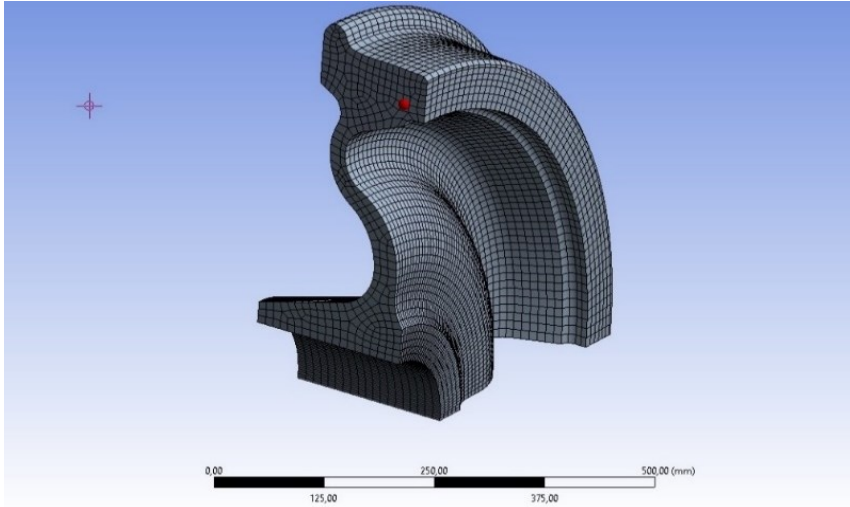


Fig. 5. Finite element model

Setting solver:

- direct solver with fixed setting step and automatic control of convergence.
- Computer parameters:
- processor: Intel Core i7 3,3 GHz (6 core)
 - memory (RAM): 64 GB

4.3 Results

On the basis of the analysis performed, the maximum value of the braking temperature was determined at 485 °C at 500 seconds due braking by cast iron block, which is at the end of the second braking. The temperature was 143 °C after cooling. The maximum temperature was determined at 500 seconds at 572 °C due braking by composite block. The temperature was 164 °C after cooling.

The temperatures in the cross section of the rail wheel, at selected points (Fig. 6), are shown in Fig. 7 and Fig. 8. These points were chosen so that the distribution of temperatures and stresses in the cross section of the wheel can be monitored.

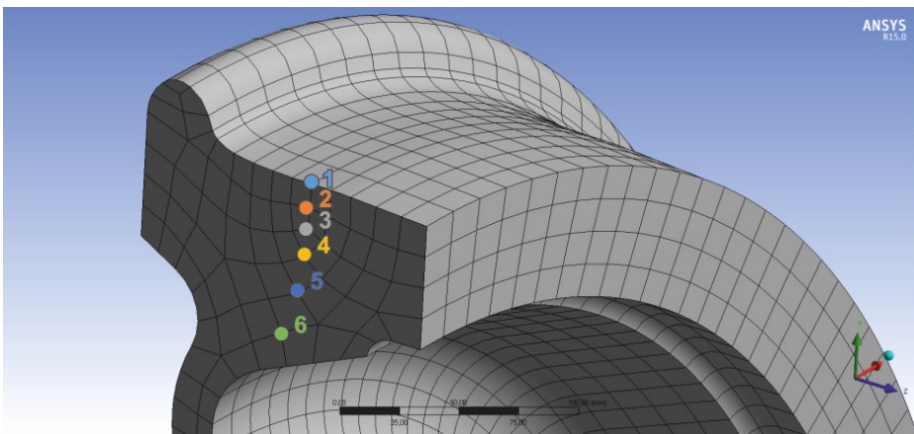


Fig. 6. The selected points, where were evaluated the temperatures and stresses

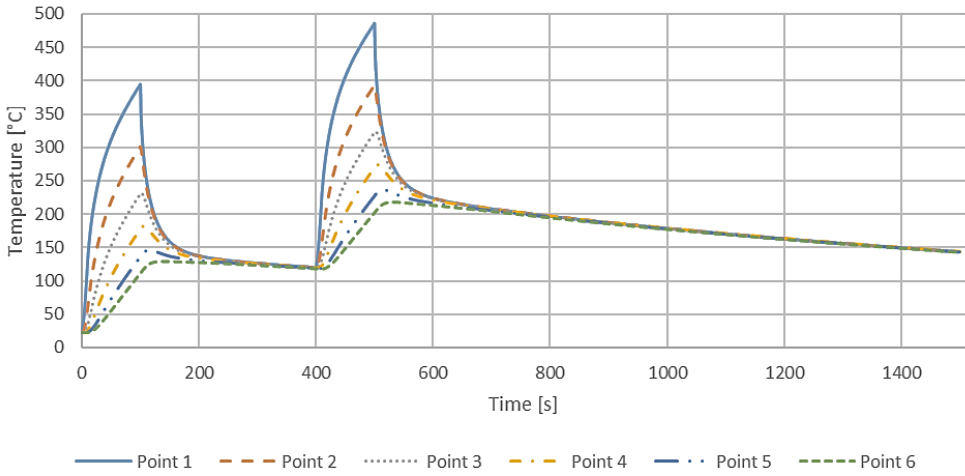


Fig. 7. Dependence temperature to time in selected points – cast iron block

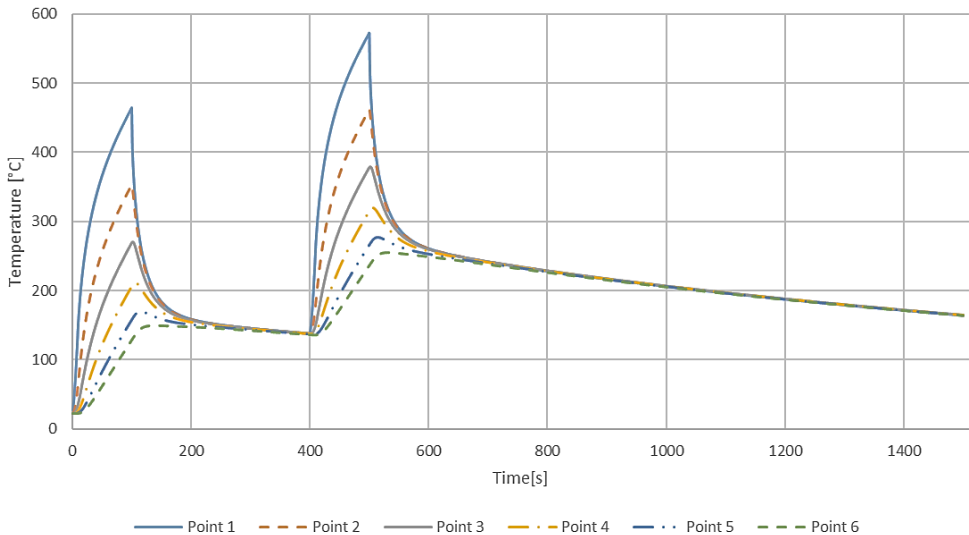


Fig. 8. Dependence temperature to time in selected points – composite block

5 Calculation of equivalent stress

On the basis of the thermal transient analysis, it was possible to detect the course of the reduced stresses in the braked railway wheel, which were caused by the thermal load. We could use the parameters from the previous thermal transient analysis thanks the ANSYS program.

Stress value is 90 MPa, determined by HMM theory on the wheel tread in time 1500 seconds. In other measured points, the value is around 24 MPa when braking by cast iron block. Stress value on the wheel tread is 197 MPa in time 1500 seconds, when braking by composite block and in other point is value 29 MPa.

The course of the reduced stresses in the cross-section of the railway wheel (Fig. 6) are shown in Fig. 9 and Fig. 10.

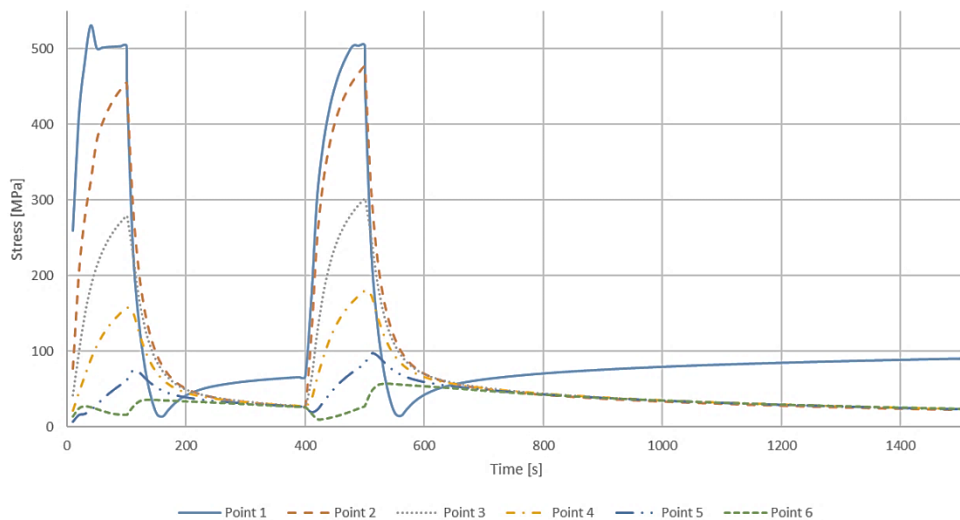


Fig. 9. Dependence stress to time in selected points – cast iron block

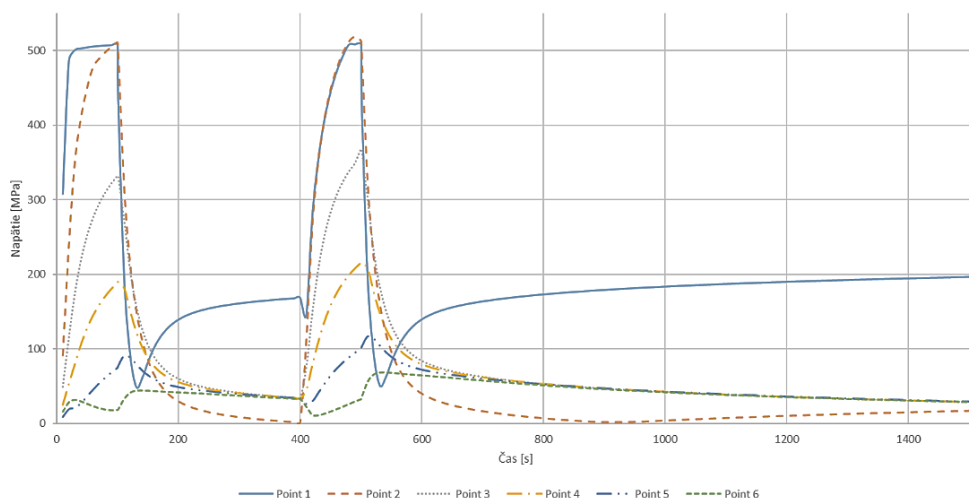


Fig. 10. Dependence stress to time in selected points – composite block

Conclusion

One possibility for identifying the impact of thermal and mechanical loading on braked railway wheel is the use of appropriate software and implementation of computer analyzes.

The article deals with the detection of structural properties braked railway wheel using a program that uses the finite element method.

On the basis of the thermal transition analysis, when the thermal fields can be determined by braking at constant heat output, a structural analysis was performed when heat inputs from the previous simulation were used as input parameters. Courses of the reduced stresses are results of simulation analyzes generated by thermal load in railway wheel. The next step is to compare the calculated values with the measured values on the

test stands. It will be necessary to fine-tune the input parameters of the simulation to match the real test values. Our task was to choose the appropriate software to detect stresses based on the temperature fields. This problem was solved in ANSYS program, which proved to be appropriate for the given task type.

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