22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

COMPARATIVE THERMO-MECHANICAL ANALYSIS OF DIFFERENT TYPES OF DISC BRAKES

J. Ziółkowska*, P. Sokolski**

Abstract: *The paper is focused on analysis of mechanical and thermal processes occurring in disc brakes during braking. For a specific example of real braking parameters the authors conducted numerical simulations of performance of two differently shaped brakes. Finite elements method was used and coupled mechanical and thermal analyses were carried out. Basing on obtained results intensity of heat generation and distribution of temperature as well as stresses level in elements of the studied subassemblies were evaluated. Comparison of scientific findings was a keystone to point out some significant remarks concerning construction of disc brakes in the view of their safe and reliable operation.*

Keywords: Disc brakes, reliability, finite elements method, thermal processes, failures.

1. Introduction

Disc brakes are common mechanisms used in modern vehicles. It is because of their braking efficiency most of all and ease of servicing (Ghadimi et al., 2013). One can distinguish their self-cleaning capability, resistance to disadvantegous thermal processes and relatively low susceptibility to brake fade as other reasons why these subassemblies are so often applied (Scieszka, 1998; Ghadami et al., 2013).

Braking systems play key role in operation of all machines and vehicles. To ensure their reliable and safe work is an indispensible demand from the very beginning phase of machinery design process.

2. Problem identification

As it was described in (Belhocine & Bouchetara, 2013; Kennedy, 1984) during braking of disc brakes almost all of the friction energy (up to 95%) transforms into heat energy. Other components like triboemission, noise, mechanical vibrations or cumulated deformation energy are much less significant but also should be taken into account during complex analysis.

Generation of heat directly causes temperature changes what implicates occurrence of different thermo-physical processes. It is especially significant on the friction surfaces. In normal conditions temperature rises up to 800 ºC (Belhocine & Bouchetara, 2013) but of course it is advised to design and operate brakes to keep this value on lower level. In extreme cases such temperature rise can influence normal radiation and heat convection what can be described as thermo-elastic instability (Scieszka, 1998).

There were plenty of experimental research focused on physics of wear processes in disc brakes (among others Laguna-Camacho et al., 2015; Eriksson et al., 1999; Eriksson et al., 2012). Accurate results and detailed description of studied phenomena are usually achieved for a price of long-lasting and very expensive tests. In this situation it is reasonable to use numerical simulations to support experimental works. Some examples of coupled mechanical and thermal FEM analysis of disc brakes behaviour is presented among others in (Belhocine & Bouchetara, 2013; Ghadami et al., 2013; Ghadami et al., 2013).

The most common solution to change the intensity of thermal processes is to use so called ventilated disc brakes. In such a part there is an additional disc separated from the original one with a special gap. Both discs are connected through a set of cooling fins. That type of construction forces changes in aerodynamical flow in its surrounding which results in higher emission of heat from brakes into the

* Eng. Justyna Ziółkowska.: Faculty of Machine Design and Operation, Wroclaw University of Technology, ul. Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, PL.

** Piotr Sokolski, PhD: Faculty of Machine Design and Operation, Wroclaw University of Technology, ul. Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, PL, piotr.sokolski@pwr.edu.pl

ambient air. Although ventilated disc brakes have more compound structure than normal ones it is more favourable distribution of heat generated while braking and also lowering the level of temperature in the brakes' components what makes them widely used in automotive industry (Ghadami et al., 2013).

3. Method

In this paper temperature and stress distributions of the disc brake have been investigated. Finite elements method was used to perform numerical simulations (in Dynamic Explicit Coupled Temperature-Displacement Module of Abaqus 6.13 software). Computations were carried out for emergency braking of a passenger car (mass 1830 kg) from speed of 178 km/h until stop in time of 7 s. Because of narrow frames of this paper calculations of basic parameters of braking unit are not included in the text.

Computational parameters of disc and pads are shown in Tab. 1.

Tab. 1: Thermal and strength parameters of disc and pads assumed in the analyses

Parameter	**Disc**	**Pads**
Density [kg/m^3]	7800	1450
Young's modulus [GPa]	209	1,4
Poisson's ratio [-]	0,29	0,24
Thermal expansion [m/mK]	1,26e-5	1,1e-5
Thermal conductivity [W/mK]	48	1,1
Specific heat [J/kgK]	452	1200

Boundary conditions for tested elements were as follows:

- Disc - rotation allowed along the direction of car's movement.

- Pads - all degrees of freedom were fixed to simulate full clamp of pads.

Two types of discs were analyzed: a normal one (first case of analyses) and a ventilated one (second case of analyses). It was assumed in this paper that evaluation of disadvantageous processes during braking will be performed for disc only and expressed by stresses (von Mises stresses as pad is made of cast steel) and temperature level. Both of analyzed brakes where designs of the authors basing on literature guidelines. The original brakes made by the producer were not the case of this work.

The authors created solid numerical models. Then finite elements to generate mesh were selected. It is usually recommended to use cubic types of elements rather than pyramidal ones. The latter are so-called not adjusted elements and for this reason the results of analyses are error-prone (Biernacki, 2014; Biernacki, 2015; Rusinski et al., 2000). Having this in mind, to create the discrete model of pads and normal disc hexahedral finite elements were used. Because of more complicated geometry it was not possible to use only such elements while meshing the ventilated disc. In some regions of this part tetrahedral finite elements were applied but they were relatively small areas comparing to the rest of the model. To lower the negative influence of usage of tetrahedral finite elements their size was lowered what is typical in such cases (Rusinski et al., 2000).

The most important results are presented in Fig. 1-4. While scale for stresses figures (Fig.1, 3) is the same (up to 500 MPa), in temperature distribution figures (Fig. 2, 4), to make pictures more clear to analyze, in first case scale was up to 500 ºC and in second case it was 200 ºC.

It was observed that in the first case of analyses both used parameters were surpassing limits after only about 3 s of simulations, it is even before half point of braking. Almost from the very beginning of the tests von Mises stresses gradually arose around a hole which is the place were the disc is mounted to the wheel and on the perimeter of the disc where the friction surfaces were located (Fig.1). Temperature values surpassed the assumed level of 500 ºC on the contact surfaces where pads were sliding along (Fig. 2). Such an intensification of tribological processes is unacceptable.

Assessing the results of the second case of analyzes it turned out that addition of extra surfaces resulted in significant lowering of temperature level in disc (Fig.4). At the time of 3,2 s, it is when first type of brake was already overheated, temperature this time was below 100 ºC. In further parts of braking, including the final one, this parameter barely exceeded 200 ºC which is way below dangerous level. Von Mises stresses were lowered as well. In the midpoint of braking there were only small local areas where level of critical stresses was exceeded. In the end of braking process this area enlarged and also stresses were too high in some parts of surfaces paired with pads (Fig. 3). It means that the proposal of modification is improving thermal phenomena sufficiently. Modification also lowered stresses but not below safe level in the entire unit. There are some small parts of disc where yield strength is reached.

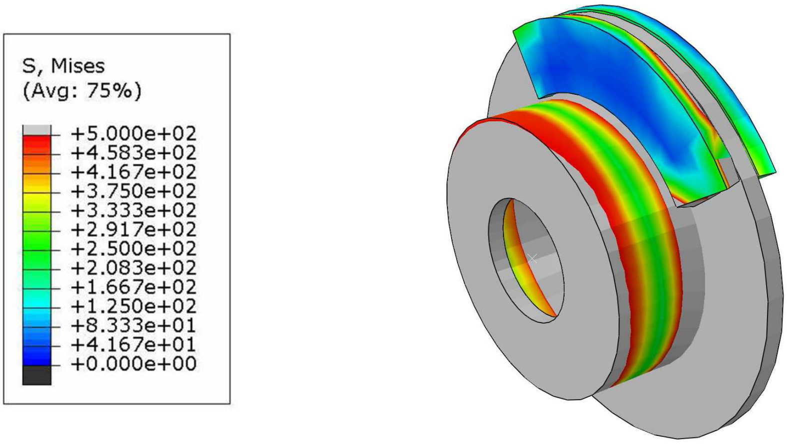

Fig. 1: Von Mises stress distribution [MPa] in disc brake unit after 3,2 s of braking in first case of analyses (detailed description in text)

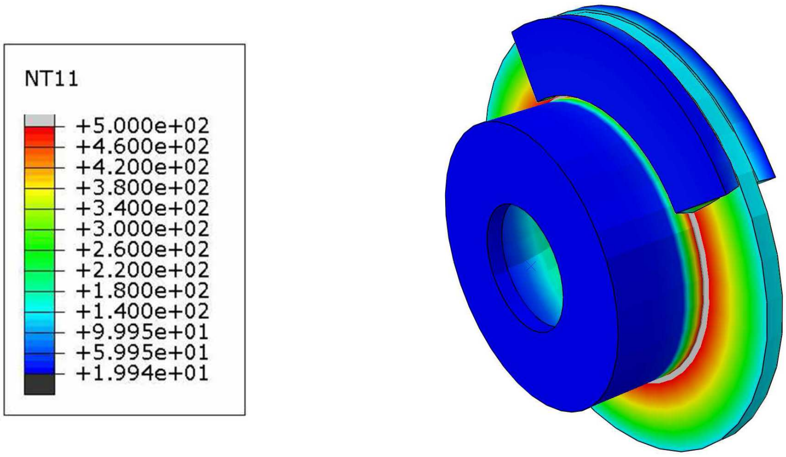

Fig. 2: Temperature distribution [ºC] in disc brake unit after 3,2 s of braking in first case of analyses (detailed description in text)

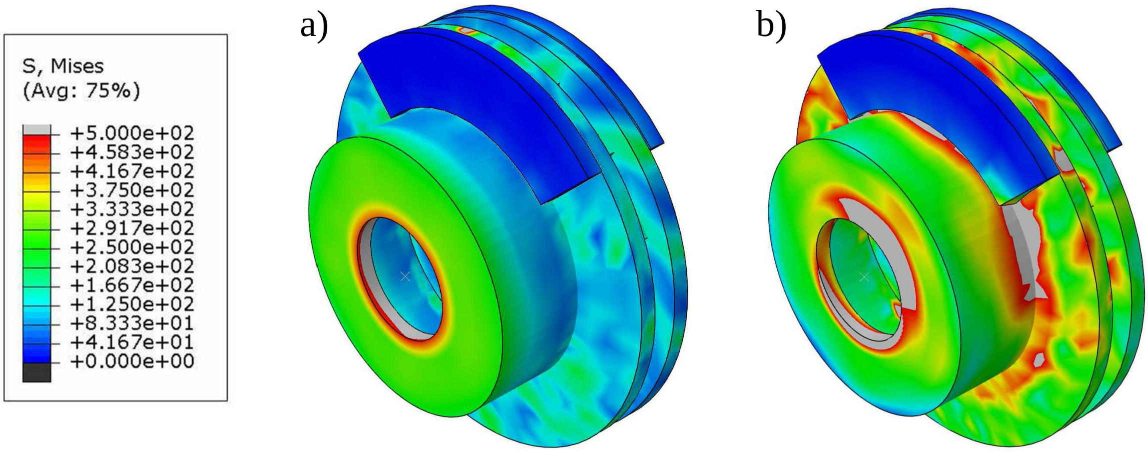

Fig. 3: Von Mises stress [MPa] distribution in disc brake unit after a) 3,2 s; b) 6 s of braking in second case of analyses (detailed description in text)

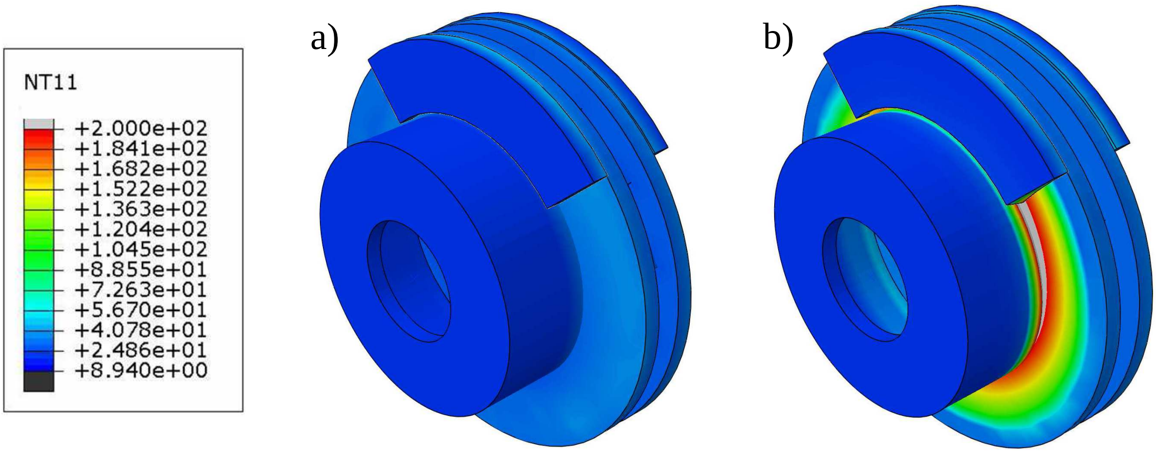

Fig. 4: Temperature distribution [ºC] in disc brake unit after a) 3,2 s; b) 6 s of braking in second case of analyses (detailed description in text)

4. Conclusions

It was observed that modification of the analyzed disc brake into the ventilated one resulted in substantial lowering of both temperature and von Mises stresses. Change of the design implied first of all changes in aerodynamic flow around the brake subassembly and heat development in its components. Thanks to that overheating within the analyzed brake was no more the problem. Additional surface turned out to strengthen the construction relevantly. Although stresses are locally over the permissible level it can be stated that the implemented modification almost fully reached expectations. Of course it also should be improved but it requires less important modifications than those which were done and they are not included in this paper because of its frames. Safety and reliability of analyzed brake units were increased.

References

Belhocine A. & Bouchetara M. (2013) Investigation of temperature and thermal stress in ventilated disc brake based on 3D thermomechanical coupling model. Ain Shams Engineering Journal, 4, pp. 475–483.

Biernacki K. (2014) Selection of the optimum tooth profile for plastic cycloidal gears. Proceedings of the Institution of Mechanical Engineers. Part C, Journal of Mechanical Engineering Science, Vol. 228, No. 18, pp. 3395-3404.

Biernacki K. (2015) Analysis of the influence of the material and design modifications on strength of the cycloidal gear system. International Journal of Precision Engineering and Manufacturing, Vol. 16, No. 3, pp. 537-546.

Eriksson M., Bergman F. & Jacobson S. (1999) Surface characterisation of brake pads after running under silent and squealing conditions. Wear, 232, pp.163–167.

Eriksson M., Bergman F. & Jacobson S. (2012) On the nature of tribological contact in automotive brakes. Wear, 252, pp.26–36.

Ghadimi B.,Kowsary F. & Khorami M. (2013) Thermal analysis of locomotive wheel-mounted brake disc. Applied Thermal Engineering, 51, pp. 948-952.

Ghadimi B., Sajedi R. & Kowsary F. (2013) 3D investigation of thermal stresses in a locomotive ventilated brake disc based on a conjugate thermo-fluid coupling boundary conditions. International Communications in Heat and Mass Transfer, 49, pp. 104–109.

Kennedy F. E. (1984) Thermal and thermomechanical effect in dry sliding. Wear, 100, pp. 453-476.

Laguna-Camacho J.R., Juárez-Morales G., Calderón-Ramón C., Velázquez-Martínez V., Hernández-Romero I., Méndez-Méndez J.V. & Vite-Torres M. (2015) A study of the wear mechanisms of disk and shoe brake pads. Engineering Failure Analysis, 56, pp. 348–359.

Rusinski E., Czmochowski J. & Smolnicki T. (2000) Advanced finite elements method in superstructures. Wroclaw University of Technology Publishing House, Wroclaw (in Polish).

Scieszka S. (1998) Friction brakes. Material, designing and tribological issues. Institute of Operation Technology Publishing House and Polygraphy Division, Radom. (in Polish)