Analysis of a brake including thermomechanical coupling

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Abstract

Brakes in cars and trucks are safety parts. Requirements not only in performance but also in comfort, serviceability and working lifetime are high and continuously rising. This supports the need for efficient methods of calculating brake systems. This paper presents numerical analyses of a braking process. Both macro and microscale models are described. Phenomenon of heat generation by friction was emphasized during dynamic calculations. An approach to modelling wear of brake pads using SPH method is also presented.

Keywords: wear, brake pads, coupled analysis, SPH

1. Introduction

The purpose of brakes is to reduce the velocity. Nevertheless the design of brakes is generally underestimated. Exact simulation of braking process is becoming increasingly important. In this paper, an attempt to numerical modeling of braking process, including concept of adhesive wear of brake pads, is presented.

2. FE model of drum brake in macroscale

Proper FE analysis is the key to predict wear. Therefore a number of FE simulations was conducted, to benchmark analysis codes, algorithms and analysis strategies. Based on this studies, LS-Dyna software was chosen. The major reasons of such choice were the following: proper description of the phenomena present during braking requires transient dynamic analysis; due to existence of large rotations, there were no real difference in time stepping between explicit and non-explicit (eg. Hubold) algorithms; contact algorithm in LS-Dyna appeared to be most efficient in coupled thermomechanical problems.

Based on real – life brakes geometries, FE models of both disk and drum brakes were created. In this paper only the drum brake is presented. The model is shown on Fig. 1. It consists of 359328 solid elements and 408419 nodes. Contact algorithm between drum and shoes was based on penalty function and penetration checking using segment to segment approach. Heat generation by friction forces was estimated assuming full (100%) conversion of mechanical work done by friction forces F_f to heat energy:

$$F_f \frac{dS}{dt} = mc_p \frac{dT}{dt} \qquad (1)$$

where: F_f – friction force, S – braking distance, t – time, m – mass, c_p – specific heat, T – temperature.

Analysis was very resource demanding, therefore only first two rotations of drum were simulated. Temperature and friction force transient changes for randomly chosen drum node are shown on the graph below (Fig. 2). Points A, B and C point out full rotations of the drum (*360°*). A repeatable pattern of a temperature change correlated with drum rotations can be easily observed. Friction force changes are also repeatable and correlated with the temperature pattern too.

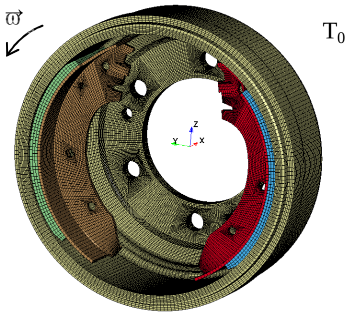

Figure 1: FE model of the brake

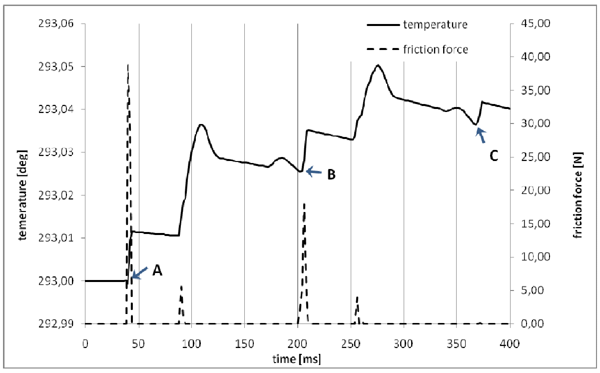

Figure 2: Temperature change in conjunction with friction force

Obtained results showed, that implemented FE algorithm is capable to handle phenomena of heat generation by friction forces. It should be stressed out, though, that proper material data and accurate FE discretisation are key factor influencing on analysis results.

3. SPH model of drum brake pad in microscale

Almost every process which occur on a brake pad surface has its beginning on the microscale of frictional bodies contact. Especially brake pads abrasive wear is the most common of all processes that occur on a friction lining surface. In order to represent it with numerical methods based on the Smooth Particle Hydrodynamics approach. SPH method has an advantage over FE methods for problems with large deformations of materials such as crash tests, fluid flows or collapse analyses. It is a meshfree particle method with Lagrangian nature, where computational information including, e.g. mass and velocity, are carried with the particles. Moreover, the main difference between classical methods and SPH is the absence of a grid. Therefore, those particles are the framework on which region the governing equations are resolved.

SPH method uses the concept of kernel and particle approximation as follows [2]:

$$\Pi^k f(x) = \int f(y)W(x-y,h)dy \qquad (2)$$

where W is the kernel function, which is defined using the function θ by the relation:

$$W(x,h) = \frac{1}{h(x)^d}\theta(x) \qquad (3)$$

where d is a number of analysed system dimensions and h is a spatial distance (smoothing length) over which their properties are "smoothed" by a kernel function.

$W(x,h)$ should be a centrally peaked function (usually the cubic B – spline) which is defined by choosing θ as:

$$\theta(u) = C\begin{cases} 1-\frac{3}{2}u^2+\frac{3}{4}u^3 &, \text{ for } |u|\le 1 \\ \frac{1}{4}(2-u)^3 &, \text{ for } 1\le|u|\le 2 \\ 0 &, \text{ for } 2<|u| \end{cases} \qquad (4)$$

where C is a constant which depends on the number of a system dimensions.

3.1. *Microscale numerical model creation process*

Firstly, based on a profilometer measurements of the friction brake pad lining sample, the points cloud surface was obtained, with the area of 4 mm × 4,4 mm. The number of points which we can acquire depends on needle leap and profilometer table shift. In this case the surface consisted of 201678 points was saved as a text file and imported into FE preprocessor (Fig. 3, 4).

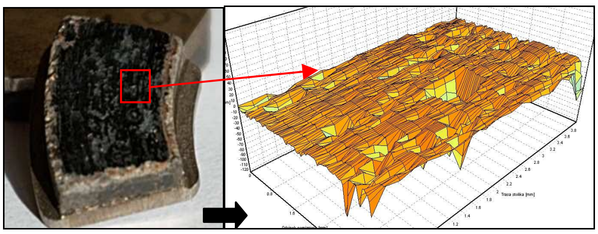

Figure 3: Pad lining sample and surface model

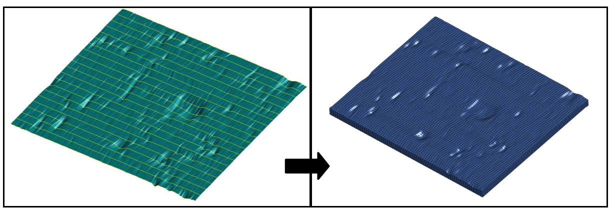

Figure 4: Geometric model and numerical model of microscale friction lining

3.2. *SPH microscale model of brake pad lining*

FE model shown above was translated into the SPH model, which consists of particles extracted from elements nodes. Brake disk was modelled as the plain surface which was in contact with SPH brake pad model (Fig. 5), with the same algorithm and penetration checking as in the macroscale approach. In order to simulate wear of a friction lining the erosion criterion was implemented, based on the shear strain failure variable [3].

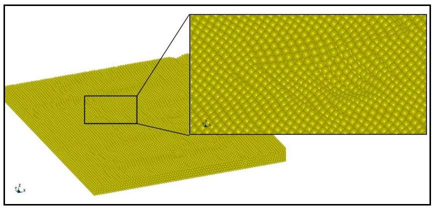

Figure 5: SPH model of brake pad lining

Performed analyses gave us results which show separate particles detaching from the model. Due to long lasting computation time only initial steps of dynamic simulation are presented (Fig. 6).

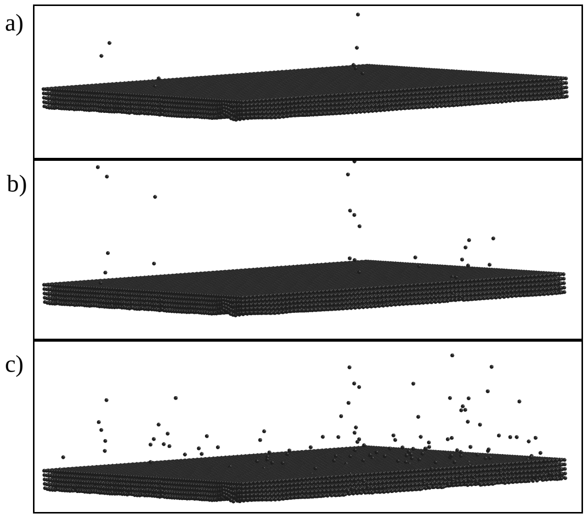

Figure 6: SPH particles detaching from the model

Obtained results showed, that implemented erosion criterion works properly and can be applied to many issues. Moreover the proposed concept of numerically wear process description will be modified in order to gain results which are more accurate and equivalent to reality. In the future experimental tests will be compared with numerical investigations which will allow us to understand wear process even more.

References

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