THERMO MECHANICAL MODELLING OF CRACKED BRAKE DISC

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The braking phenomena show that the main stress is due to the high temperature variations induced by friction between the pads and the disc. These sudden variations didn't allow the temperature to homogenize, these variations create a big problem in the disc and pads, and also this problem is called by the thermal fatigue phenomena. The main objective of this work is to study a numerical analysis by finite element method of thermal stress distribution in disc thickness caused by heat flux distribution, and its effect on life and brake fading. The results are employed for determent the stress distribution in the disk, the temperature evolution in the disk body and the variation of stress intensity factor in the crack tip.

Keywords: Brake Disc, Crack, Stress, Thermal Strain, Temperature.

Nomenclature:

ε_{ij}: Strain tensor; σ_{ij}: stress tensor, E: Young module.
ν: Poisson coefficient, α : Heat conductivity.
ΔT: Temperature variation; m(x) is the weight function
Γ_c is the perimeter of the crack tip.
σ_{yy}: stress, K_I: stress intensity factor, M : Mass of vehicle.
v_0: Start velocity. a : Deceleration, t_b : Braking time.
r_d : Effective radius of the braking disc. r_w : Radius of the wheel.
μ : Friction coefficient disc/pad. A_c : braking pad area.
$\dot{Q}$: Heat flux., F_{disc}: the force applied to the disc, t_z: simulate time.

1. Introduction

Mechanical power transmission systems become more reliable with time; this trend is true for all transport systems. Design firms find that the conception and integration problems, increasingly exploiting the results of digital models. Numerical modeling becomes an essential tool to save time and facilitate the shaping of different complex systems. The mechanism studied a braking system

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and exhibits premature cracking. It includes components that help them to stop the movement of the wheels. The brake disc constitutes a mechanical device of great importance in the architecture of the vehicle. The different elements constitute of the brake disc system are: the disc and the two pads.

The thermal overloading of this kind is caused by excessively frequent, intermittent sharp braking. This results in high levels of alternating thermal loads which give rise to internal stresses leading to a crack through the brake disc (Fig. 1).

The cooling capacity of the disc during successive braking becomes insufficient to decrease the surface temperature to the initial value; these results are in a cumulative energy and therefore a higher area temperature, for this reason we tried to determine the stress and temperature field on the disc also at the crack tip, as well as the crack propagation under a thermal cyclic loading. This work gave us the influence of the temperature on the crack's propagation.

During the braking phase, temperatures and thermal gradients are very high. These generate stresses and deformations are manifested by the appearance of cracks. This phenomenon is not new in the field of railway, aeronautical or automobile transport. A significant number of modelling and experimental works has been carried out in recent years to try to understand the mechanisms of dry rubbing. The modeling of dry contact remains a topical issue, especially when it comes to braking devices. Lee stated that inconsistent dissipation of heat inside the brake disc could cause deformation of the disc [1]. O.I. Abdullah used the finite element method used to study the contact pressure and stresses during the full engagement period of the clutches using different contact algorithms [2]. Ali Belhocine identified the thermal effects on the structure and contact behavior between the disc and pads assembly using a finite element method, he determined the distribution of temperature, strain and Contact pressure variation [3]. The analysis of the temperature and stresses of the disc brakes under specific loads was calculated by Marko Reibenschuh, the study was applied on the application of the centrifugal load for two braking cases, braking at a standstill on a Flat surface and downhill braking. In both cases, Marko Reibenschuh was considered the main limiting condition that was the heat flux introduced on the brake surface of the disc and the brake clamps. Two different discs were used, one new (not used) and one with port allowed [4]. A study was carried out by Sung-Soo Kang in order to analyze the geometry of the fins in the motorcycle disc brakes. So as to analyze the thermal characteristics of brake disc, in the same work. It has been shown that, during the braking process the ventilated disc will have a lower temperature than the solid disc also the effect of increasing and decreasing temperature are depending on the fin area generated in the part of the disc flange [5].

Fig. 1. Crack in brake disc.

2. Analytical model

2-1. Thermo mechanical model:

In order to know the elastic stress field induced by this heat flux field, we use the law of linear thermo elastic behavior assuming a behavior Macroscopic isotropic:

$$\varepsilon_{ij} = \frac{1+v}{E}\sigma_{ij} - \frac{v}{E}\sigma_{kk}\delta_{ij} + \alpha\Delta T\delta_{ij} \quad (1)$$

From the stress field in our disc σ yy (x, t), Bueckner and Rice [7, 9] showed that it is possible to use the weight function method to obtain the stress intensity factor

$$K_I = \int_{\Gamma_c} \sigma_{yy}(x,t)m(x)dx \quad (2)$$

Where m(x) is the weight function and Γ_c is the perimeter of the crack tip, K_I: the intensity factor it is a parameter that determines the stress in crack tip.

2-2. Dynamic vehicle:

The principle of the model generally in the literature takes into account at each moment the evolution of the disc-pads contact. This distribution of the contact makes it possible to calculate and apply the heat flux created by friction. Furthermore, the weight distribution of the vehicle is taken into consideration. It is assumed that 60% of the braking forces are supported by the front brakes (both rotors), or 30% for a single disc [6].

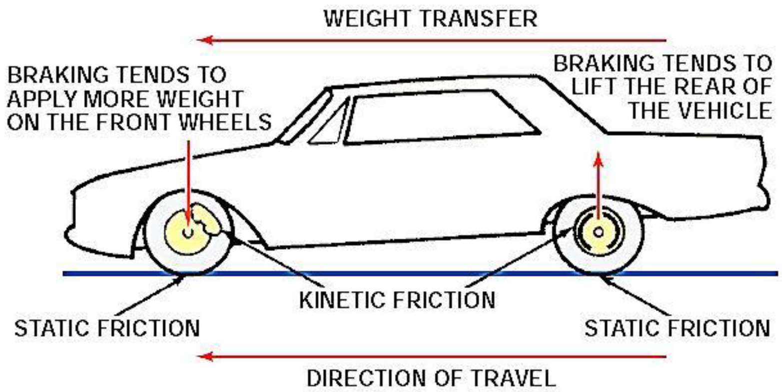

Fig. 2. Friction acting on a vehicle

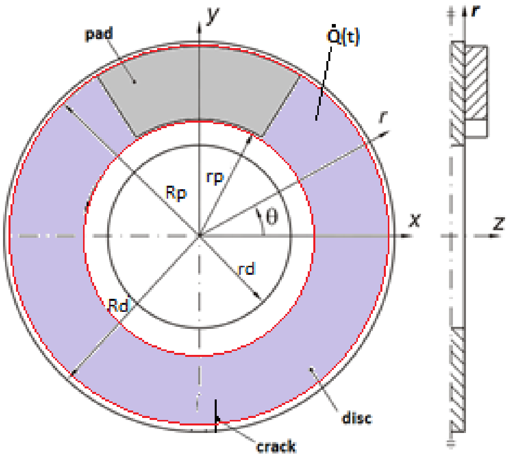

Fig. 3. Diagram of a braking system with a cracked disc

The kinetic energy for a wheel considering a constant deceleration is:

$$0.3 * \frac{1}{2} * M * v_0^2 = \int_0^{t_z} p(t)dt = 2 * F_{disc} \int_0^{t_z} v_{disc}(t)dt \tag{3}$$

$$F_{disc} = \frac{0.3 * \frac{1}{2} * M * v_0^2}{2 * \frac{r_d}{r_w}\left(v_0 * t_z - \frac{1}{2} * a * t_z^2\right)} \tag{4}$$

The instantaneous heat flux into the brake disc face is directly calculated by the next expression:

$$\dot{Q}(t) = F_{disc} * v_{disc}(t) = F_{disc} * \frac{r_d}{r_w} * (v_0 - a * t) \tag{5}$$

The energy changes as equal to the heat flux on the disc surface. This ratio is used to calculate the thermal load on the brake disc. The other data used for the analysis is shown in Table 1.

Table 1:

Vehicle Characteristic [3]

Mass of vehicle - M[kg]	1385
Start velocity – v_0 [m/s]	40
Deceleration – a [m/s^2]	6.15
Braking time – t_b [s]	6.5
Simulate time – t_z [s]	30
Effective radius of the braking disc – r_d [mm]	100.5
Radius of the wheel – r_w [mm]	380
Friction coefficient disc/pad – μ [/]	0.2
Surface of the braking pad A_c – [mm^2]	5246.3

2-3. Material proprieties:

The brake disc is made of carbon steel, in the standardized state are subjected to rotational bending stresses. Therefore, there is a failure risk due the propagation of fatigue cracks. The main characteristics of the material are presented in table 2.

Table 2:

Material properties [3]

	Value
Heat conductivity – λ [W/m.^{0}C]	57
Density – ρ [kg/m^3]	7250
Specific heat – c_p [J/kg.^{0}C]	460
Elastic Module – E [GPa]	210
Poisson coefficient – ν [/]	0,3

3. Numerical model:

In our study, we started with a crack initiation of a depth of a_0 = 6mm, with a stress ratio R = 0 and an applied thermal stress (heat flux) on the zone of contact between the disc and the pads during three braking cycles of the ABS system of the vehicle which is illustrated in figure 2 (it’s a cycle of ABS system bracking. and we predicted the temperature after 30s). It is assumed that the coefficient of heat transfer of the convection is 100 W / m^{2}K.
The rotation of the disc is taken into account, keeping its imposed and constant angular velocity ω = 157.89 rad / s [8].

In our case, the effect of moisture in the air and heat transfer by radiation is not taken into account. Figure 4 shows three ABS braking cycles.

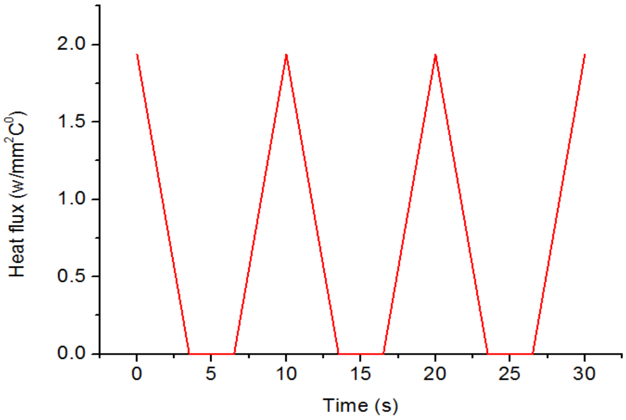

Fig. 4. ABS braking cycle [3]

The model of the finite elements of the cracked disc is presented in figure 5. The disc is modeled by a three-dimensional mesh of an 8-node quadratic element and must be correctly fixed by the 6 holes.

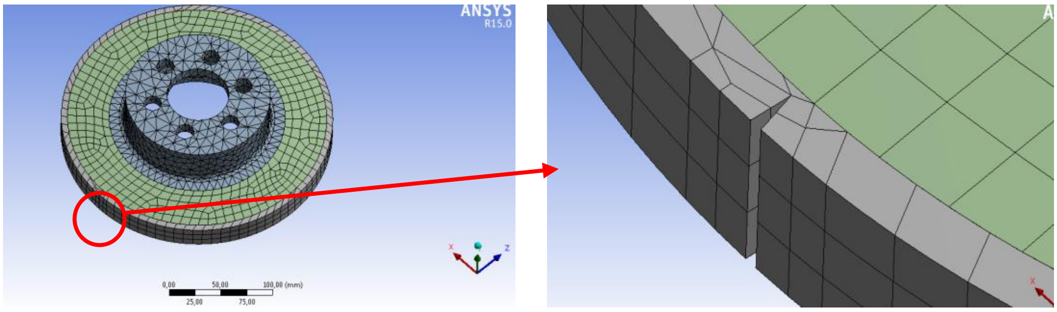

Fig. 5. Geometrical model of the cracked brake disc

4. Results and discussion

4-1. Evolution of the temperature

This analysis of the crack disc was implemented for the ABS braking example. The following temperatures were taken into account; the initial temperature of the disc, the fixation of the disc and the ambient temperature were all equal to 22 ° C [10].

In this mode of braking, it can be seen that the temperatures in the disc increase strongly after each braking and begin to decrease exponentially. As the number of repetitions of braking, increases the higher maximum temperatures. The initial state of the disc changes after each cycle, the stops t = 3.5s allow only partial cooling. After each cooling phase, the disc starts to warm up again. It can be seen that, towards the fixing holes the temperatures drop rapidly so that these points are not thermally charged and the effect of the thermal loads on the hub itself is not taken into consideration, It can be seen from the figure 8 that the change is in the temperature at the crack tip varies in the same way as the variation on the disc but its amplitude remains small compared to the amplitude of the temperature of the disc, Core to the surface. The maximum value recorded at the crack head reaches 386.76 ° C on the surface and the value of 338.2 ° C at the core which is less than the maximum value detected on the disc 507 ° C.

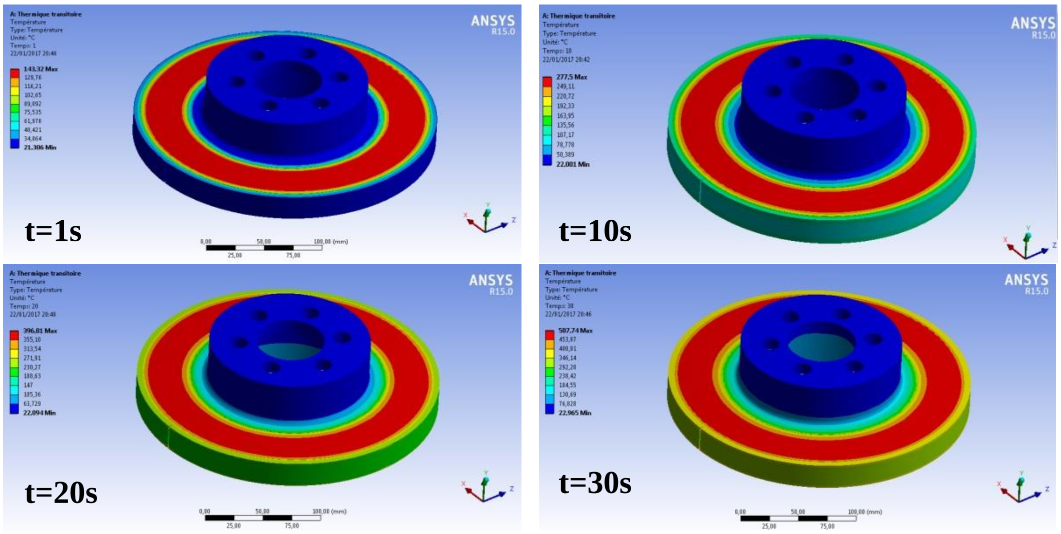

Fig. 6. Temperature distribution field

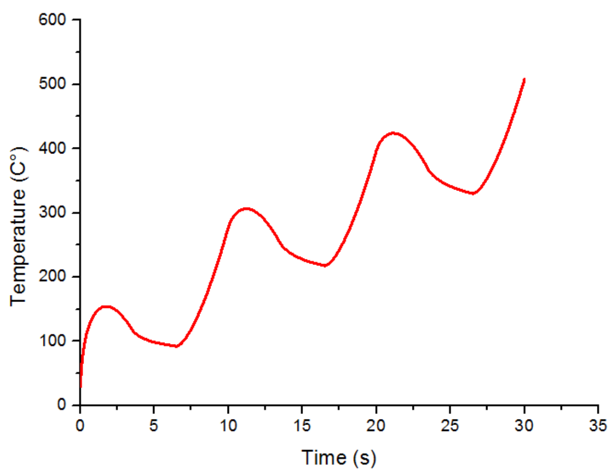

Fig. 7. Time-dependent temperature field.

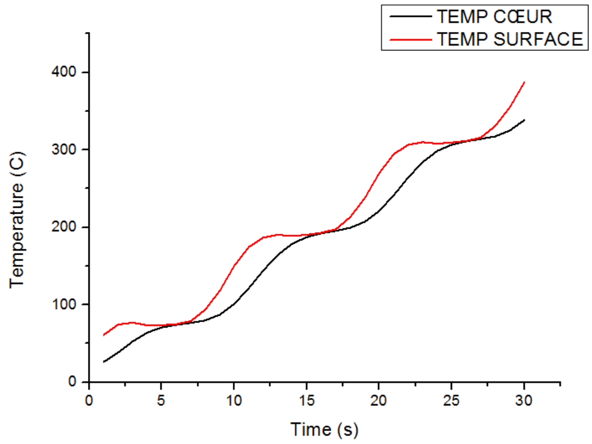

Fig. 8. Temperature field at the top of crack.

4-2. Von Mises Stress

On the basis of the analysis performed, the Von Mises stress was obtained. The results for the crack disc are shown in figure 9. The maximum value recorded during this simulation is in the contact area between the disc and pads (external and internal contact area of the disc), it’s of the order of 19.098MPa at t = 30s. It has been taken into consideration that the stress is on the outer ring and at the fixing bores also in the bowl connection area equal to 2.2028 MPa has not significantly increased during the applied braking type. This fact means that, the contact is not applied to these zones.

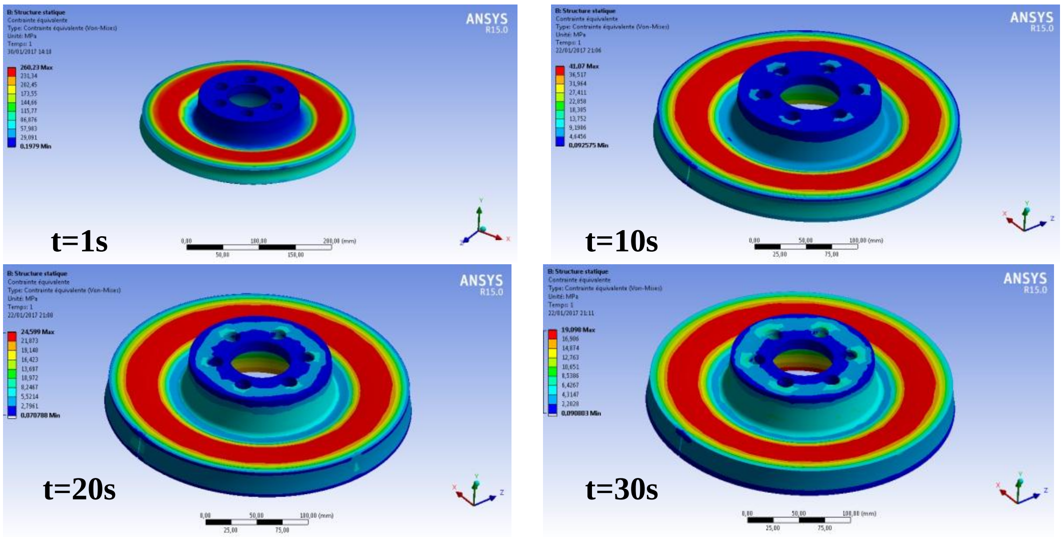

Fig. 9. Stress distribution field

4-3. Stress Intensity Factor

Fig. 10 plots the evolution of the FIC as a function of time for a crack of depth a = 6 mm. Also, figures 10 and 11 show successfully the distribution of the KI as a function of time on the disc and in the crack tip.

As the evolution of stresses at the top of the crack, the FIC has a transient regime at the beginning of simulation and harmonic until the end. KI is positive when the surface of the disk is in tension, which explains the phenomenon of opening of the crack in the region of the contact. When the surface of the disk is in compression, KI is negative, which illustrates the closing phenomenon during this simulation.

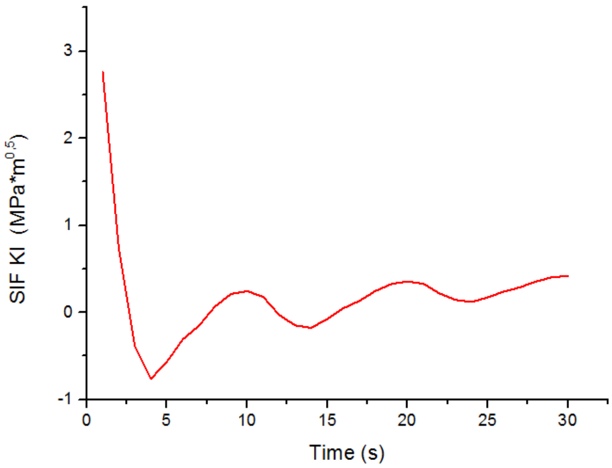

Fig. 10. Distribution of the KI as a function of time.

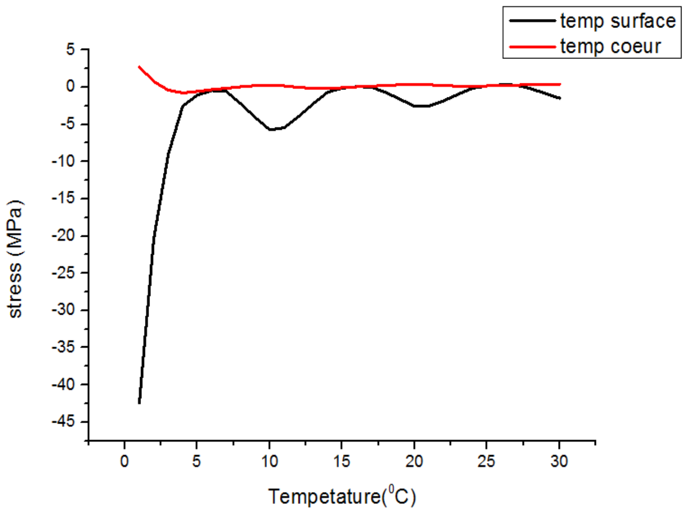

Fig. 11. Distribution of the KI at head of the crack.

5. Conclusions

From the results of the simulation, it can be stated that although the selected model of the disc brake is cracked at the runway with predetermined crack characteristics but the temperature results and the equivalent stress of Von Mises as well as the stress intensity factor remain below the elastic limit. Moreover, this tendency will ensure a greater safety and a longer service life of the braking member, but this remains a problem to be treated in order not to fall with the phenomenon of the sudden rupture of the disc. However, the analysis did not take into account the effects of mechanical stresses such as shear, residual stresses. It is concluded that, the braking mode with a cooling phase has a very positive influence on the propagation of cracks in the disc.

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