Study on Transient Thermal Analysis of a Disc Brake During Braking and Releasing Periods

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Abstract

Automobile braking system is considered as one of the most important safety systems in modern vehicles as its main intention is to stop or decelerate the vehicle. The frictional heat generated between the pads and disc during the braking application can cause various negative impacts, such as brake fade, thermal cracks, disc thickness variation and wear.

This project studied the transient thermal behavior of a disc brake system during the braking phase and the followed releasing period. A three-dimensional finite element model with a moving heat source was developed with COMSOL Multiphysics to predict the temperature distribution in the disc braking system, including two pads, a rotor disc, bolts, and a section of the shaft. The maximum surface temperature on the contact surface has been found to increase in the braking period and then decrease as the rotor slows down and further decrease during the releasing period. The maximum temperature on the contact surface depends on both the car velocity and deceleration rate. The effects of convective and radiative heat transfer are also studied. It is found that heat is mainly dissipated through convective heat transfer at the disc surfaces.

Introduction

With the development of new technologies in the automotive industry, vehicles have become more and more efficient. The most significant aspect of an automobile is its brake system, which must slow the vehicle quickly and reliably under varying conditions. There are many types of brake systems that have been used since the inception of the motor car, but in principle they are all similar. The main function of brake system is to decelerate the vehicle by transforming the kinetic energy of car into thermal energy using the friction between the brake disc and the brake pads and this heat must be effectively and efficiently dissipating to the surroundings and to the brake components.

So while applying the brake the rotor is decelerated and the heat is generated, this generated heat is absorbed to the rotor and some amount will be dissipated to the surrounding air. The Dissipation of heat transfer occurs in three modes convection, conduction and radiation. Due to convection the heat dissipation is greatly high compared to other heat transfer modes like conduction and radiation.

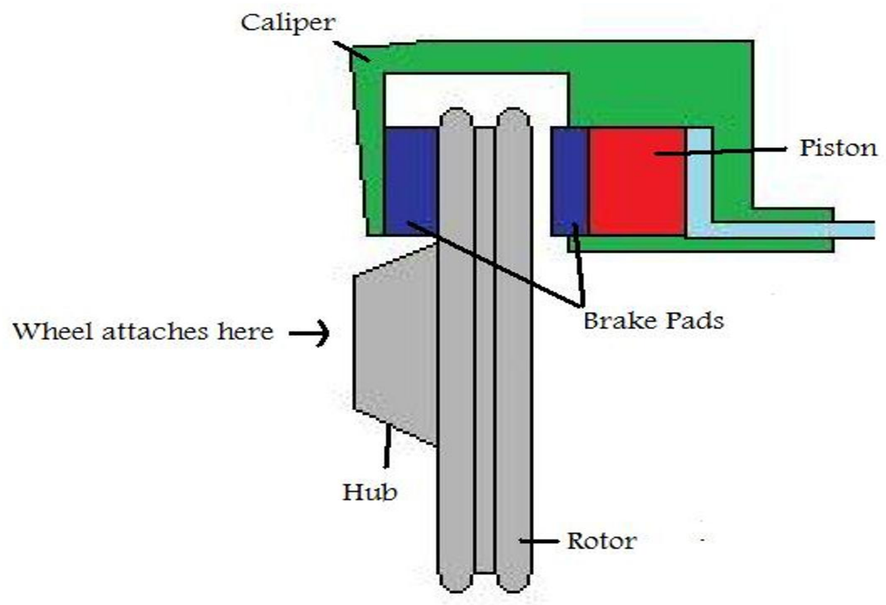


Fig. 1. Disc Brake System [1]

The disc brakes consists of a rotor and caliper at each wheel, while apply braking more fluid comes into action and piston gets displaces and caliper pushes the brake pads and the pads press against the rotor surface.

Numerical Model

The transient temperature field of the pad and the disc will be governed by the heat conduction equation

$$\rho C_p \frac{\partial T}{\partial t} + \nabla(-k\nabla T) = -\rho C_p \mathbf{u}\cdot\nabla T$$

where k represents the thermal conductivity, C_p is the specific heat capacity and **u** is the velocity field of the rotor.

Frictional heat generation at the contact surfaces is given by

$$q(r,t) = -f_f V_d(r,t) = -\frac{mR^2\alpha}{8r_m A} r\omega(t)$$

Where f_f is the frictional force per unit area, V_d is the relative velocity between rotor disc and pad, m is the car's mass, R is the wheel radius, ω is the angular velocity, and α is the angular acceleration, A is the pad surface area.

The heat dissipation from the disc and pad surfaces to the surrounding air is done by both convection and radiation:

$$q_{diss} = -h(T-T_{ref}) - \varepsilon\sigma(T^4 - T_{ref}^4)$$

where ε is emissivity, σ is Stefan Boltzmann constant. h is convective film coefficient given by

$$h = \frac{0.037k}{l}\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33} = \frac{0.037k}{l}\left(\frac{\rho l V}{\mu}\right)^{0.8}\left(\frac{C_p\mu}{k}\right)^{0.33}$$

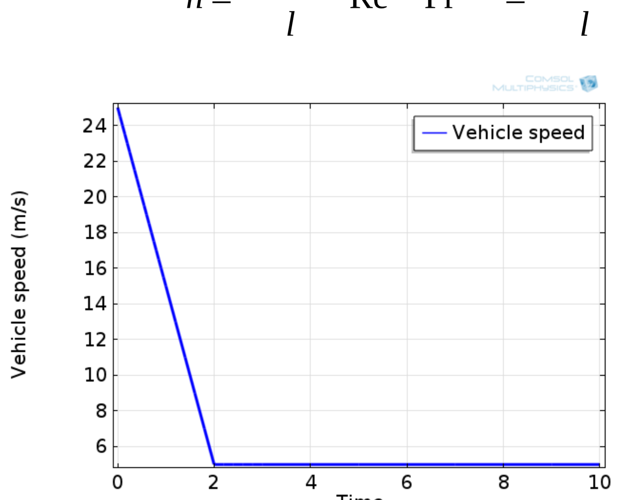


Fig. 2. Velocity during a braking and releasing period

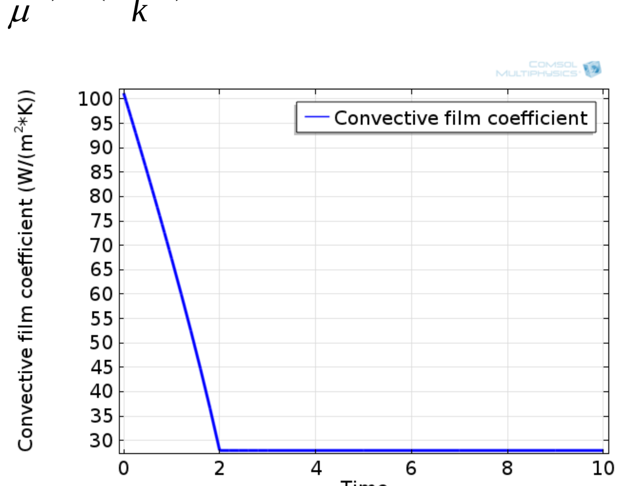


Fig. 3. Heat transfer coefficient during the braking and releasing period

Table 1. Design Parameters

Disc Brake: Specifications	
Initial vehicle speed	25[m/s]
Radius of wheel	245 [mm]
Radius of disc	172.5 [mm]
Car mass	1900 [Kg]
Braking time	2 [s]
Pad surface area	4910 [mm²]
Initial temperature	300 [K]

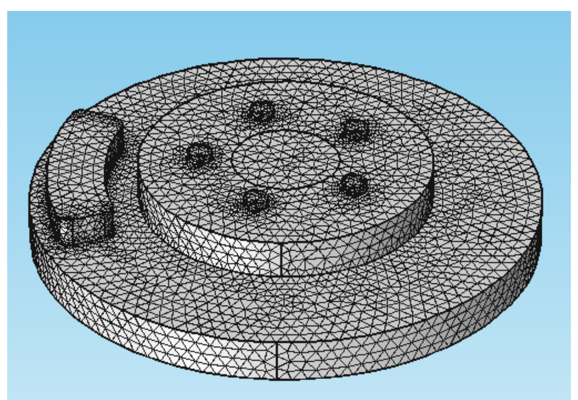
Table 2. Material Properties

Material Properties	Pad	Disc and others
Density	2000 [Kg/m³]	787[kg/m³]
Heat capacity	935[J/(kg*K)]	449[J/(kg*K)]
Thermal conductivity	8.7[W/(m*K)]	82[W/(m*K)]
Emissivity	0.8	0.28

Problem Specification and Simulation Results

The braking system consists of two pads and a rotor disc connected with bolts and section of shaft. In the first study, a car of 1900 kg travels at 25 m/s (90 km/h) is slowed down to 5 m/s (18 km/h) in 2s when pads are pressed to the disc surfaces. The car will continue to travel at 5 m/s for 8 s after the pads are released. The velocity profile of the car is shown in Fig. 1. The disc brake information and the material properties of pad, dics and other components are listed in Table 1 and 2. Fig. 4 shows the model meshed with 85,572 tetrahedral elements.

Fig. 4. Meshing of the disc brake



Figures 5 shows the inside and outside surfaces of the braking system at 1.2s. It can be seen that the maximum temperature is at the pad and disc contact surfaces. As shown in Fig. 6, the frictional heat is mainly absorbed by the rotor disc during the braking phase, heat is then gradually dissipated to the surrounding air by convection and radiation. Therefore, the temperature distribution is very close at the two sides of the disc. The heat dissipation to the surroundings are mainly by convection as shown in Fig. 7. During the braking phase, the rotor surface temperature is higher than during the releasing period, these leads to a higher convection and radiation heat transfer rate in the first 2s. Higher velocity also gives a higher heat transfer coefficient for higher convective heat transfer.

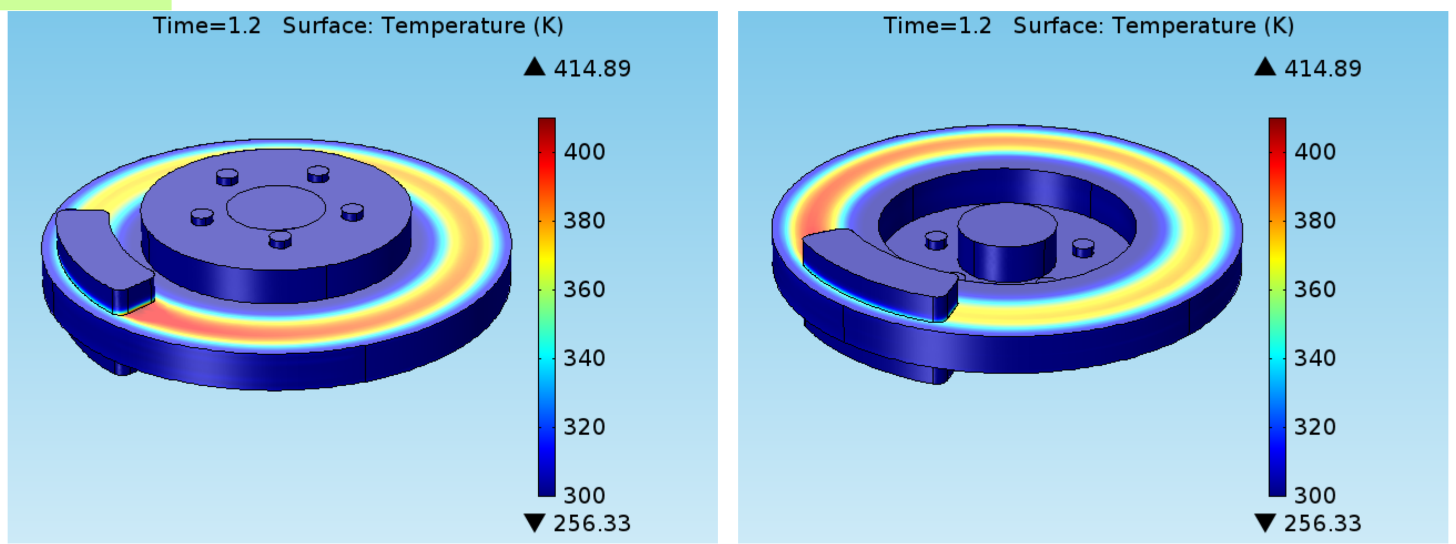


Fig. 5. Surface Temperature at 1.2s: outside (left) and inside (right)

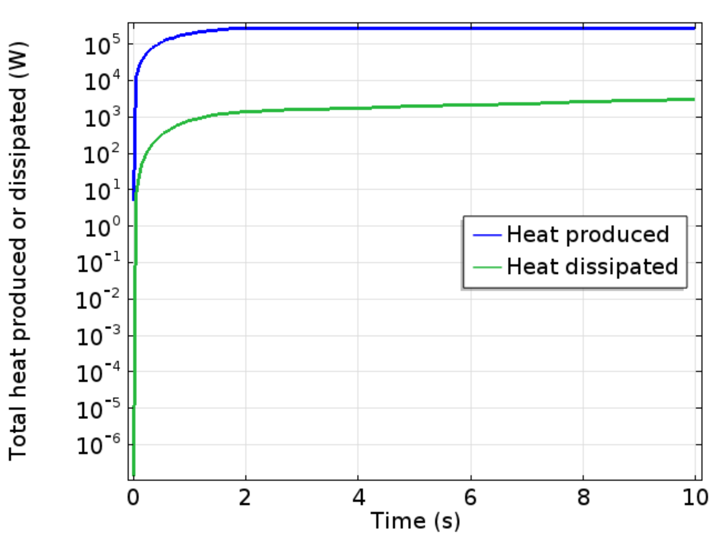


Fig. 6. Heat production and dissipation

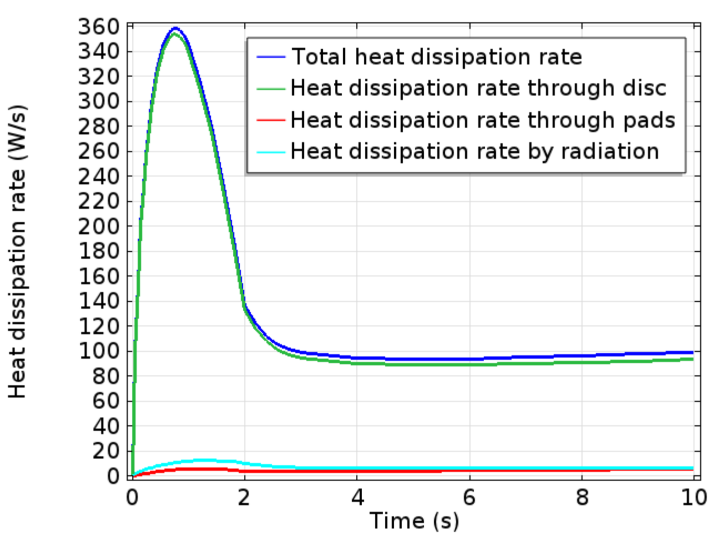


Fig. 7. Heat dissipation rate

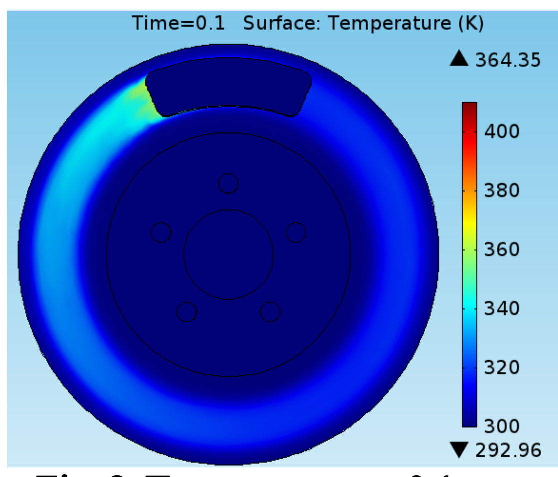


Fig. 8. Temperature at 0.1s

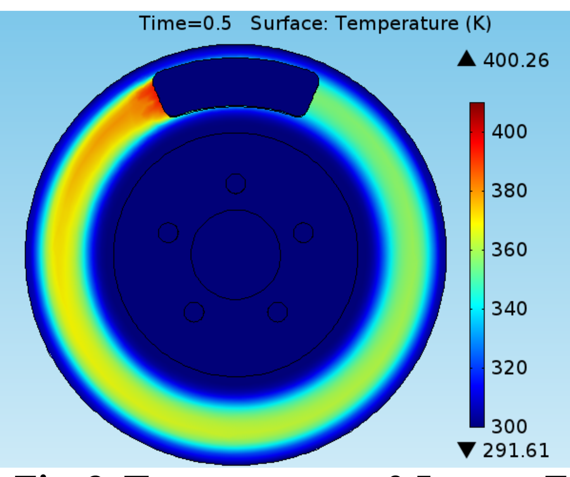


Fig. 9. Temperature at 0.5s

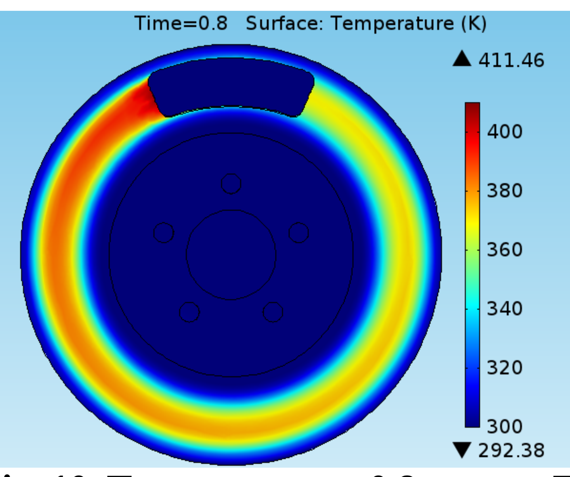


Fig. 10. Temperature at 0.8s

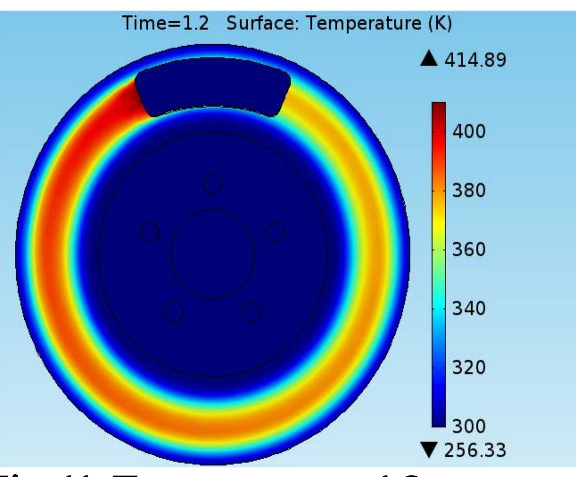


Fig. 11. Temperature at 1.2s

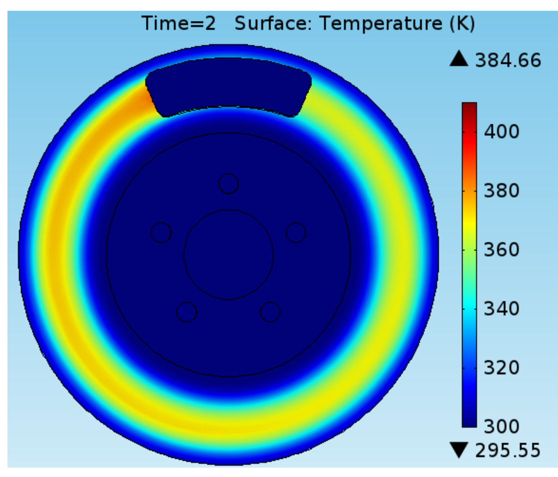


Fig. 12. Temperature at 2s

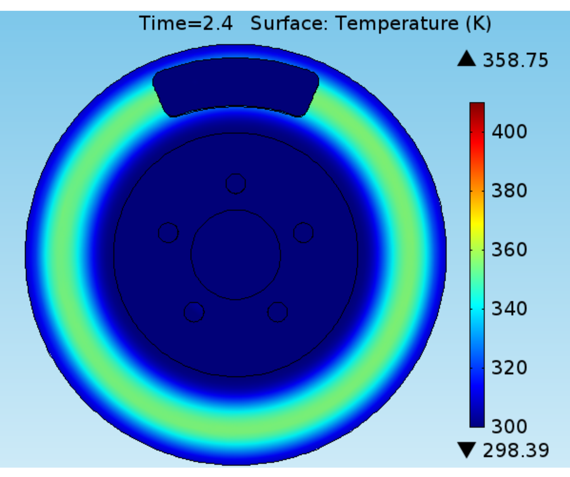


Fig. 13. Temperature at 2.4s

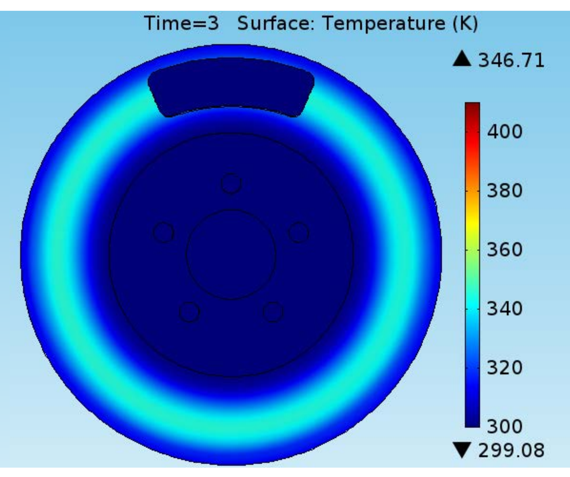


Fig. 14. Temperature at 3s

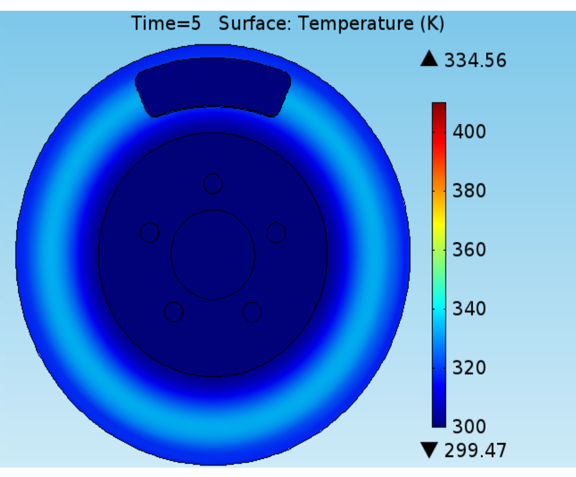


Fig. 15. Temperature at 5s

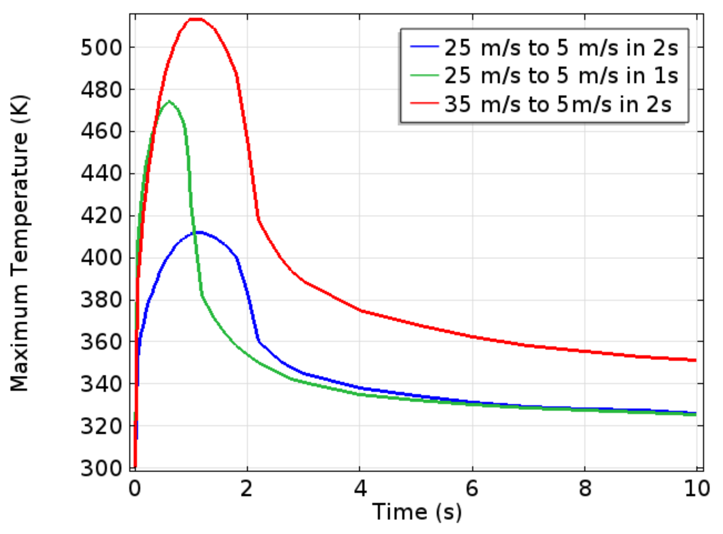


Fig. 16. Maximum temperature at the contact surfaces

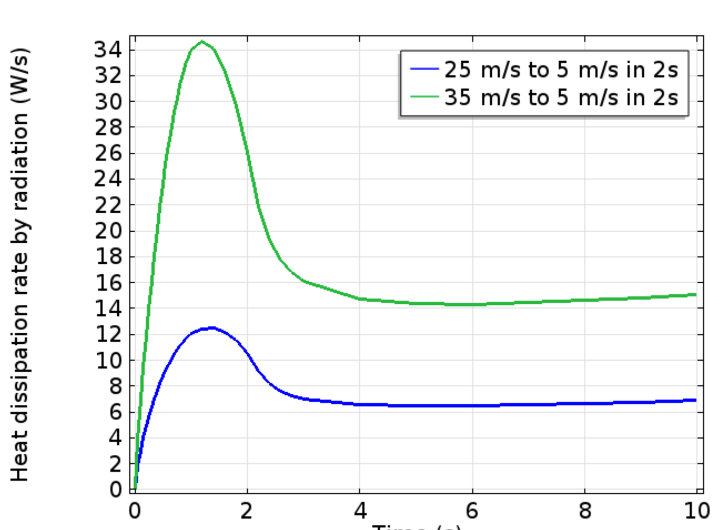


Fig. 17. Heat dissipation by radiation

Figures 8-12 shows the heating and cooling and cooling of the disc surface through a time sequence of temperature distributions. The rotor surface quickly reaches the maxim temperature of 414.89K at 1.2s and then gradually decreases to 384.66K at 2s as the rotor slows down. It continues to cool after the braking is released. The maximum temperature of the rotor at different time steps is also shown in Fig. 16.

The effect of braking duration and the initial velocity on the maximum contact surface temperature is also studied in Fig. 16. Heat dissipation by radiation increases as the contact surface temperature increases as shown in Fig. 17 for the case of braking 35 m/s to 5 m/s in 2s.

Conclusions

In this study transient thermal analysis of disc brake during braking and releasing have been conducted in COMSOL Multiphysics. The effect of heat transfer by conduction through the rotor disc, pad, bolts, and shaft, by convection at the pad and disc surfaces, and by radiation at the pad and disc surfaces have been studied. It is found that the majority of heat is transferred by conduction to the rotor disc during the braking phase. Heat is also dissipated from the disc surface by convection. The effect of braking duration and the initial velocity on the maximum contact surface temperature is also studied. It is found that a hard braking will cause higher temperature.

References

[1] J.H. Choi and I. Lee, Transient thermos elastic analysis of disc brake in frictional contact, Journal of Thermal Stresses, 26, (2003)223-244
[2] COMSOL manual.
[3] http://www.interauto.lt/imgbank/tcd/10/332110.jpg