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Thermal Analysis of Disc Brake Using Comsol

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ABSTRACT : This work deals with the analysis of heat generation and dissipation in a disc brake of an car during panic braking and the following release period by using computer aided engineering software for three different materials of rotor disc. The objective of this work is to investigate and analyze the temperature distribution of rotor disc during operation using COMSOL MULTIPHYSICS. The work uses the finite element analysis techniques to predict the temperature distribution on the brake disc and to identify the critical temperature of the brake rotor disc. All three modes of heat transfer (conduction, convection and radiation) have been analyzed. The results obtained from the analysis shows that different material on the same retardation of the car during panic braking shows different temperature distribution. Thus, a comparison is made between three different material used for brake disc and the best material for making brake disc based on the rate of heat dissipation have been suggested.

Keywords: Disc Brake, Brake pads, FEA, Comsol Multiphysics

I. INTRODUCTION

One of the most important control systems of an automobile is Brake system. They are required to stop the vehicle within the smallest possible distance and it is done by converting kinetic energy of the vehicle into heat energy by friction which is dissipated into atmosphere. The main requirements of brakes are: The brakes must be strong enough to stop the vehicle within the minimum possible distance in an emergency. But, this should also be consistent with safety. The driver must have a proper control over the vehicle during emergency braking and the vehicle must not skid. The brakes must have good antifade characteristics and their effectiveness should not decrease with constant prolonged application. A disc brake assembly consists of Disc rotor that rotates with the wheel, Calliper assembly attached to the steering knuckle, Friction materials (disc pads) that are mounted to the calliper assembly.

This work shows the heat generation and dissipation in a disc brake of an ordinary car during panic braking and the following release period. As the brakes slow the car, they transform its kinetic energy into thermal energy, resulting in intense heating of the brake disc. If the discs overheat, the brake pads stop working and, in a worst-case scenario, can melt. Braking power starts to fade already at temperatures above 600 K.

In this work, the car (1600 kg) initially travels at 25 m/s (90 km/h) when the driver brakes hard for 2 s, causing the vehicle's eight brake pads to slow the car down at a rate of 10 m/s^2. The wheels are assumed not to skid against the road surface. After this period of time, the driver releases the brake and the car travels at 5 m/s for an additional 8 s without any braking. In this work, three different materials have been used for making brake disc. The questions to analyze with the work are :

(*i*) How hot do the brake disc and pads become during the braking stage?

(*ii*) How much do they cool down during the subsequent rest?

II. LITERATURE REVIEW

Gao and Lin (2002) presented Transient temperature field analysis of a brake in a non-axisymmetric three-dimensional model [1]. The disk-pad brake used in an automobile is divided into two parts: the disk, geometrically axisymmetric; and the pad, of which the geometry is three-dimensional. Using a two-dimensional model for thermal analysis implies that the contact conditions and frictional heat flux transfer are independent of *y*. This may lead to false thermal elastic distortions and unrealistic contact conditions. An analytical model is presented in this paper for the determination of the contact temperature distribution on the working surface of a brake. To consider the effects of the moving heat source (the pad) with relative sliding speed variation, a transient finite element technique is used to characterize the temperature fields of the solid rotor with appropriate thermal boundary conditions. Numerical results shows that the operating characteristics of the brake exert an essentially influence on the surface temperature distribution and the maximal contact temperature.

Voller, *et al.*(2003) perform a Analysis of automotive disc brake cooling characteristics [2]. The aim of this investigation was to study automotive disc brake cooling characteristics experimentally using a specially developed spin rig and numerically using finite element (FE) and computational fluid dynamics (CFD) methods. All three modes of heat transfer (conduction, convection and radiation) have been analyzed along with the design features of the brake assembly and their interfaces. The influence of brake cooling parameters on the disc temperature has been investigated by FE modelling of a long drag brake application. The thermal power dissipated during the drag brake application has been analysed to reveal the contribution of each mode of heat transfer.

Choi and Lee, (2004) presented a paper on Finite element analysis of transient thermoelastic behaviors in disk brakes [3]. A transient analysis for thermoelastic contact problem of disk brakes with frictional heat generation is performed using the finite element method. To analyze the thermoelastic phenomenon occurring in disk brakes, the coupled heat conduction and elastic equations are solved with contact problems. The numerical simulation for the thermoelastic behavior of disk brake is obtained in the repeated brake condition. The computational results are presented for the distributions of pressure and temperature on each friction surface between the contacting bodies.

Qi and Day (2007) discussed that using a designed experiment approach, the factors affecting the interface temperature, including the number of braking applications, sliding speed, braking load and type of friction material were studied [4]. It was found that the number of braking applications had the strongest effect on the friction interface temperature. The real contact area between the disc and pad, i.e. pad regions where the bulk of the kinetic energy is dissipated via friction, had a significant effect on the braking interface temperature. For understanding the effect of real contact area on local interface temperatures and friction coefficient, finite element analysis (FEA) was conducted, and it was found that the maximum temperature at the friction interface does not increase linearly with decreasing contact area ratio. This finding is potentially significant in optimizing the design and formulation of friction materials for stable friction and wear performance.

Eltoukhy and Asfour (2008) present a paper on Braking Process in Automobiles: Investigation of the Thermoelastic Instability Phenomenon. In this chapter a case study regarding a transient analysis of the thermoelastic contact problem for disk brakes with frictional heat generation, performed using the finite element analysis (FEA) method is described in details. The computational results are presented for the distribution of the temperature on the friction surface between the contacting bodies (the disk and the pad) [5].

Also, the influence of the material properties on the thermoelastic behavior, represented by the maximum temperature on the contact surface is compared among different types of brake disk materials found in the literature, such as grey cast iron (grey iron grade 250, high-carbon grade iron, titanium alloyed grey iron, and compact graphite iron (CGI)), Aluminum metal matrix composites (Al-MMC's), namely Al_2O3 Al-MMC \and SiC Al-MMC (Ceramic brakes).

Zaid, *et al*. (2009) presented a paper on an investigation of disc brake rotor by Finite element analysis. In this paper, the author has conducted a study on ventilated disc brake rotor of normal passenger vehicle with full load of capacity [6]. The study is more likely concern of heat and temperature distribution on disc brake rotor. In this study, finite element analysis approached has been conducted in order to identify the temperature distributions and behaviors of disc brake rotor in transient response. ABAQUS/CAE has been used as finite elements software to perform the thermal analysis on transient response. Thus, this study provide better understanding on the thermal characteristic of disc brake rotor and assist the automotive industry in developing optimum and effective disc brake rotor.

Talati and Jalalifar (2009), presented a paper on Analysis of heat conduction in a disk brake system [7]. In this paper, the governing heat equations for the disk and the pad are extracted in the form of transient heat equations with heat generation that is dependant to time and space. In the derivation of the heat equations, parameters such as the duration of braking, vehicle velocity, geometries and the dimensions of the brake components, materials of the disk brake rotor and the pad and contact pressure distribution have been taken into account. The problem is solved analytically using Green's function approach. It is concluded that the heat generated due to friction between the disk and the pad should be ideally dissipated to the environment to avoid decreasing the friction coefficient between the disk and the pad and to avoid the temperature rise of various brake components and break fluid vaporization due to excessive heating.

III. MODELLING AND MESH GENERATION

Modeling of the complete disc brake is generated using COMSOL software. The model of brake disc as a 2D with dimensions is shown in figure. The disc has a radius of 0.125 m and a thickness of 0.020 m.

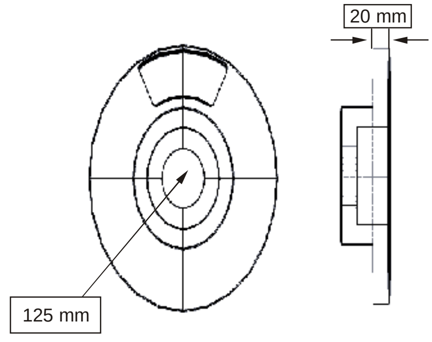

Fig. 1. 2D drawing of disc brake.

Meshing is done for converting a continuous object into finite no. of parts known as elements. Meshing of the brake disc and pad has been done using Comsol Multiphysics. The element used for meshing is of tetrahedral shape.

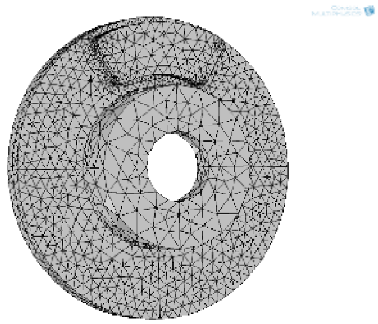

Fig. 2. Meshed model of disc brake.

Material Properties of Brake Disc and Pad

Material Properties	Cast iron	Al. alloy	Ceramic Al_2O_3 (99.5 %)	Asbestos
Density [kg/m^3]	7200	2700	3800	2000
Heat capacity [J/(kg*K)]	460	840	600	935
Thermal conductivity [W/ (m*K)]	50	140	27.5	8.7
Emissivity	0.44	0.40	0.80	0.80

Input Parameters

Description	Symbol	Expression/ values
Initial vehicle speed	v0	25[m/s]
Vehicle acceleration	a0	–10[m/s^2]
Wheel radius	r_wheel	0.25[m]
Initial angular velocity, disc	omega0	v0/r_wheel
Angular acceleration, disc	Alpha	a0/r_wheel
Vehicle mass	m_car	1600[kg]
Area of pad	A_pad	4770e-6 [m^2]
Pad's centre of mass radius	r_m	0.1025[m]
friction	f_f	m_car*r_wheel2*alpha/ 4*r_m*A_pad)
Braking time	t_brake	2[s]

FEA RESULTS OF DISC BRAKE

The FEA result of the disc brake has been analyzed and compared with different following existing materials for disc.

Case 1- Cast Iron Disc

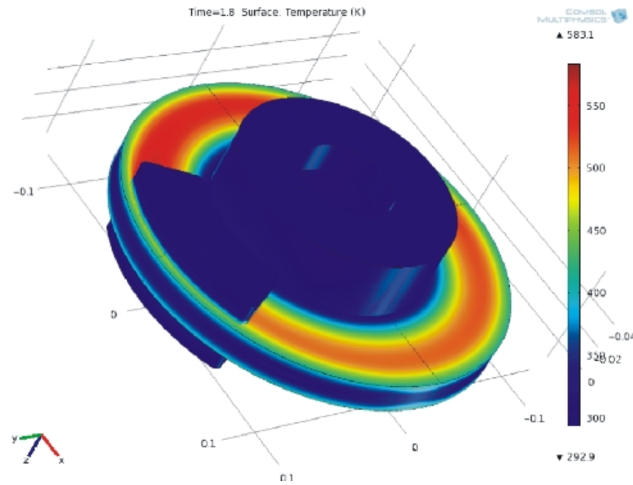

Fig. 3. Surface temperature of the cast iron brake disc and asbestos pad just before releasing the brake (t = 1.8s).

To investigate the position of the hot spot and the time of the temperature maximum, it is helpful to plot temperature versus time along a line from the center to the pad's edge as in Figure 4. We can see that the maximum temperature is approximately 605.3 K. The hot spot is positioned close to the radially outer edge of the pad. The highest temperature occur approximately 1.2 s after engaging the brake.

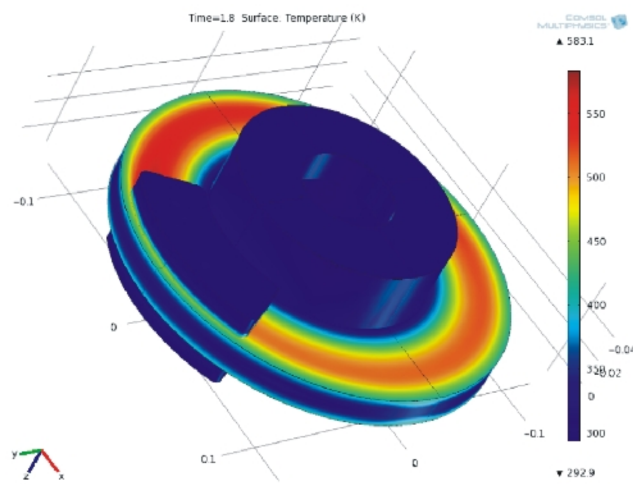

Fig. 4. Temperature profile along the indicated line at the cast iron disc surface (z = 0.020m) as a function of time.

To investigate how much of the generated heat is dissipated to the air, the surface integrals of the produced heat and the dissipated heat have been studied. These integrals give the total heat flux (J/s) for heat production, Qprod, and heat dissipation, Qdiss, as functions of time for the brake disc. The time integrals of these two quantities give the total heat (J) produced and dissipated, respectively, in the brake disc. Figure 5 shows a plot of the total produced heat and dissipated heat versus time. We can see that 8 s after disengagement the brake has dissipated only a fraction of the produced heat. The plot indicates that the resting time must be extended significantly in order to dissipate all the generated heat.

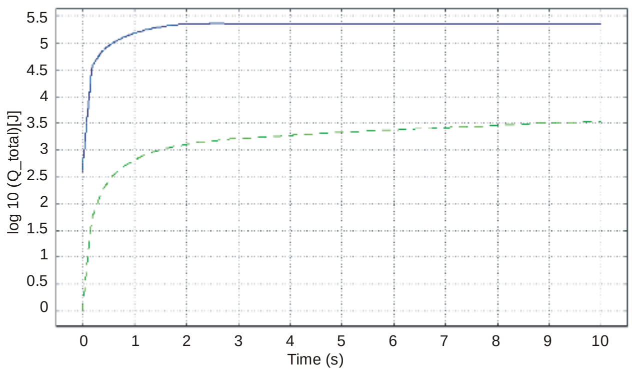

Fig.5. Comparison of total heat produced (solid line) and dissipated (dashed).

Case 2. Aluminum Alloy Disc

Similarly we see all the result for aluminum alloy disc. The maximum temperature is approximately 559.2K.

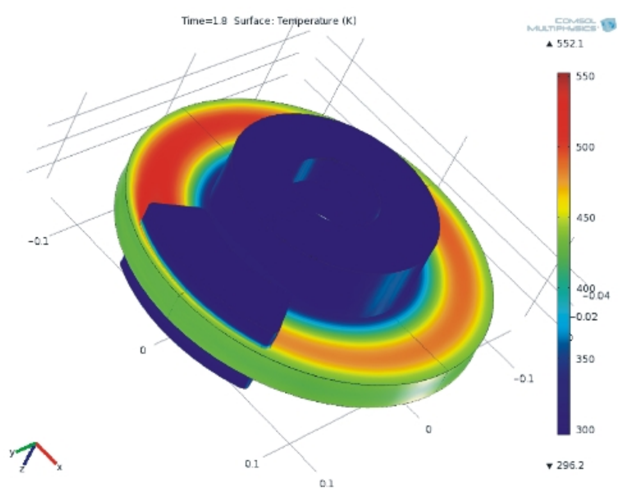

Fig.6. Surface temperature of the aluminum alloy brake disc and asbestos pad just before releasing the brake (t = 1.8 s).

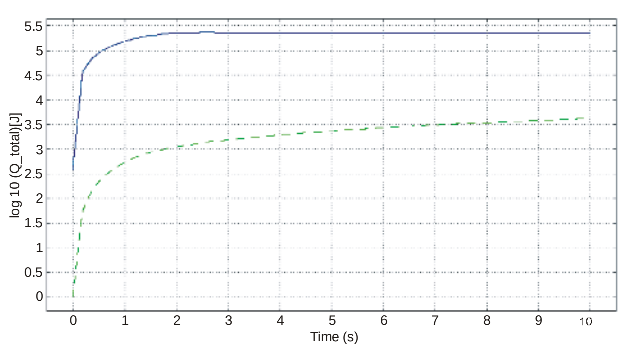

Fig. 7. Temperature profile along the indicated line at the aluminum alloy disc surface as a function of time.

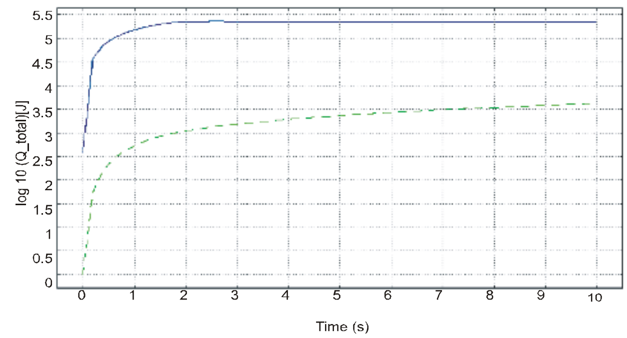

Fig. 8. Comparison of total heat produced (solid line) and dissipated (dashed).

Case 3- Ceramic Al_2O_3 Disc

Similarly we see all the result for Ceramic Al_2O_3 disc. The maximum temperature is approximately 769K.

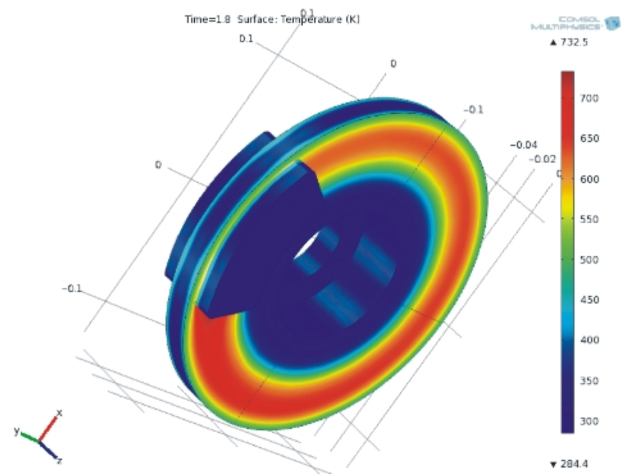

Fig. 9. Surface temperature of the Ceramic Al_2O_3 brake disc and asbestos pad just before releasing the brake (t = 1.8s).

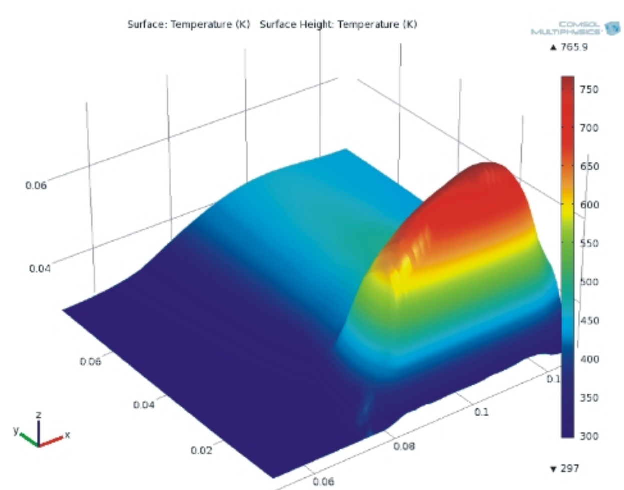

Fig. 10. Temperature profile along the indicated line at the Ceramic Al_2O_3 disc surface as a function of time.

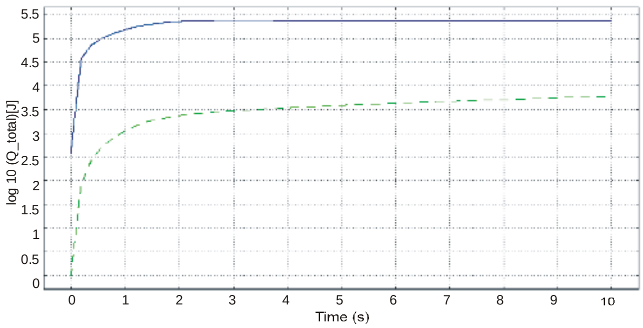

Fig. 11. Comparison of total heat produced (solid line) and dissipated (dashed).

Comparison of FEA results of present model

According to above result for different material a comparison table is made which shows the temperature at different time for different materials.

Table 1. Temperature of brake disc of different material at different time.

Times Materials	1.2 Temp. [K]	1.8 Temp. [K]	1.0 Temp. [K]
Cast iron	605.3	583.1	407.8
Aluminium alloy	559.2	552.1	435.9
Ceramic Al_2O_3 (99.5%)	769	732.5	459.7

IV. CONCLUSION

On the basis of the current work, it is concluded that the different material has different quality as used for brake disc.

(*i*) The cast iron has the maximum temperature produced is about 605.3K which is low as compare to ceramic but the rate of losing the heat is good as compare to aluminium alloy.

(*ii*) The aluminium alloy has the maximum temperature produced is about 559.2 K which is lowest as compare to other but the rate of losing the heat is very low as compare to other material.

(*iii*) The ceramic has minimum weight among other material and the maximum temperature produced is about 769K which is highest as compare to other material but the rate of losing the heat is greatest in ceramic as compare to other material.

So from above we can conclude that cast iron can be used in brake disc which will give moderate cooling at low temperature as compare to other material. Ceramic has good cooling characteristics but it is costly then the other material and it cannot be machined easily. So it can be used in racing cars where high temperature will produced.

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