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Research Article

Thermodynamic Analysis in Brake Pad Adhesive Layer of the Disk Brake

Ju Song Jong, Phyong Il Jang, Jun Il Jin, Chol Hyok Song, Kwang Il Ri*

Faculty of Materials Science and Technology, Kim Chaek University of Technology, Pyongyang, DPR Korea

Abstract

It is inevitable that the temperature at the braking pads is increasing during the braking phase. It not only reduces the friction coefficient of the pad but also affects the adhesion between the brake pad and the steel fixing plate, which can have a critical effect on the braking performance. To enhance the adhesion efficiency and reduce the amount of adhesive, this study has been conducted at the simulation of the coupled thermal-stress in the adhesive layer between the brake and the fixing plate during braking to determine the optimum adhesive layer structure. The simulation analysis was carried out using ABAQUS, a finite element analysis (FEA) software. The brake pad material is the carbon fiber-reinforced carbon and silicon carbide composite (C/C-SiC), high-performance friction material. As adhesives for adhesion of the brake pad and steel fixing plate, Araldite 2011 was coated on the inclined-check adhesive layer (with width of 7 mm and space of 2, 4, 6, 8, 10 mm) and the analysis of thermal-stress simulation was carried out on the adhesive layer. The suitable spacing dimensions of adhesive layer which is thermo-mechanically stable saving adhesives were determined. The result is 4 mm (maximum Mises stress 47.6 MPa and saving 60% of adhesives).

Keywords

Braking, Adhesive Pattern, Coupled Thermal-Stress, Finite Element Analysis

1. Introduction

Brake is an important safety device that provides braking by converting kinetic energy of vehicles into other kinds of energy.

During the braking, the brake pad and the disk are rubbed each other producing a lot of heat [1]. The heat from braking is applied to brake disc and pad, and almost is transferred to brake disc [2]. The heat from braking causes several negative practices such as evaporation of braking fluid, failing in braking capacity, reduction of friction coefficient and production of thermal stress, etc. So it is important to release this heat as quickly as possible [3]. Hence, a simulation analytical study is performed to predict the heating state of brake disk and pad by heat produced from braking [4-7].

Experimental and simulation studies [8-14] to design a brake rotary plate with aeration holes to minimize the heating by brake friction heat and to evaluate the thermal stress state have been performed a lot. The literature [15] determined the structural dimensions of adhesive layer coated in inclined-check pattern to reduce the amount of adhesives by simulating and analyzing the state under the static compression loading. During the braking process friction heat is produced, so thermodynamic study must be performed.

*Corresponding author: GI.Li803@star-co.net.kp (Kwang Il Ri)

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This paper determines the structural design of thermo-structural stable adhesive pattern by performing thermo-mechanical simulation of adhesive cohesion of brake pad and disk during braking using ABAQUS, a finite element analysis program.

2. Modeling

2.1. Geometric Model

The model of disk brake with aeration holes of car is used. Its geometric dimension is given in Table 1.

Table 1. *Geometric Structure of Brake Rotary Plate and Brake Pad.*

Symbol	Value
Maximum radius of rotary plate, R_{max} (mm)	266
Minimum radius of rotary plate, R_{min} (mm)	133
Contact area of pad, S_p (mm^2)	30410
Contact area of disk, $S_{d,}$ (mm^2)	3447
Thickness of adhesive layer, d (mm)	0.2

Each braking pad has one route and it is connected by the fixing plate and adhesives.

The object discussed is the brake pad, so the geometric model of the brake disk can be condensed as shown in Figure 1 to save the simulation computation time.

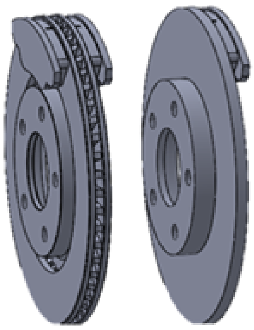
(a) (b)

Figure 1. *Structure and Miniature of the Brake for Analysis;(a) Structure; (b) Miniature.*

The brake is symmetrical to the central plane of the brake disk, so only half part is used for symmetrical simulation (aeration holes and chamfers are removed).

The adhesive layer with 0.2mm thickness is newly added to simulate the thermal and stress state in the adhesive layer.

For the structural optimization of the adhesive layer, the space d between adhesives of the adhesive pattern shown in Figure 2 is set as the design parameter.

Figure 2. *Pattern of the Brake Adhesive Pad.*

2.2. Meshing

The model is divided into single areas and the whole area consisting of hexahedral elements. "Thermal-stress" elements are used.

The details for meshing are given in Table 2 and Figure 3 shows the meshing result.

Table 2. *The Details for Meshing.*

	Element type	Size of element (mm)	Number of element
Rotary plate	Coupled temp-displacement	4	23055
Brake pad	Coupled temp-displacement	3	5485
Fixed plate	Coupled temp-displacement	3	4092
Adhesive layer	Coupled temp-displacement	0.04	3653

Figure 3. *The Meshing Result of the Brake Model.*

2.3. Materials

Araldite 2011 is used as adhesives to couple C/C-SiC brake friction pad and steel plate together.

C/C-SiC is used for the brake friction pad, cast iron for the rotary plate and steel for the fixed plate.

The physical properties of the brake friction pad, the fixing steel plate and adhesives are given in detail in Table 3.

The maximum working temperature of adhesives is 120 ℃ and its tensile strength is 60MPa.

Table 3. Physical Properties of Brake Friction Pad, Rotary Plate, Fixed Plate and Adhesives.

	Friction pad	Rotary plate	Fixed plate	Adhesives
Density, ρ(Kg/m^3)	2500	7250	7200	1150
Elastic modulus, E(GPa)	1	138	138	2.3
Poisson ratio, υ	0.2	0.28	0.28	0.36
Coefficient of thermal expansion, α(10^{-6}/K)	5	10.85	10.85	7
Thermal conductivity, k(W/m ℃)	12	57	50	5
Specific heat, C(J/Kg ℃)	900	460	447	700

2.4. Simulation

Simulation is performed for 10 seconds in 2 stages.

The first stage is the braking-starting and stopping process at an initial speed of 28 m/s for 3.3 s.

The second stage is the process to release heat from braking to other parts and surrounding air for the rest of time.

The number of steps, minimum time increment, maximum time increment and initial time increment for simulation analysis in two stages are listed in Table 4.

Table 4. Initial, Minimum and Maximum Time Increment in Two Stages of Simulation.

	Initial increment	Maximum Increment	Minimum Increment	Number of steps
First stage	0.0001	0.005	0.00001	40000
Second stage	0.001	0.01	0.0001	50000

2.5. Initial, Boundary and Loading Condition

The temperature of all the parts at the beginning of braking is set as 25 ℃.

A brake pressure of 4 MPa is applied to the brake rear plate.

Brake rotary plate is defined as a rigid body and its motion is considered with respect to the center point of rotary plate, i.e. angular velocity is changed on the center point of rotary plate.

The angular velocity is linearly decreased to zero at the initial angular velocity during the braking time, and the force pressing the friction pad during the braking is kept constant.

Heat release by heat radiation is not considered in simulation.

2.6. Contacting Condition

The parts in contact with each other in the brake are adhesives and the back plate of pad, and the friction surfaces of pad and rotary plate.

The friction coefficient between pad and brake rotary plate is given as follows.

μ=0.3.

When defining the contact relation in Abaqus, the heat producing condition by friction can be defined, i.e. the fraction of friction work being converted into heat and the fraction of heat transferred to the two contact surfaces should be defined.

In the simulation, it is assumed that the friction work is totally converted into heat.

Since the properties of two contact materials and contact surfaces are different, the friction heat is not distributed to two surfaces equally. That distribution is calculated by the following equation [4].

$$\sigma = \frac{\xi_p S_p}{\xi_p S_p + \xi_d S_d} \quad (1)$$

where ξ is heat effect of two materials and calculated by the following equation.

$$\xi = \sqrt{k \rho c} \quad (2)$$

Calculating the heat distribution coefficient from the data of the physical properties of the brake disk and pad, heat of 5.6% is transferred to the pad.

3. Result and Analysis

3.1. Temperature

Temperature distributions on the adhesive layer during the braking of 10 seconds are obtained by simulation for 6 different types of adhesive layer.

Figure 4 shows temperature distribution on the brake adhesive layer for 6 types.

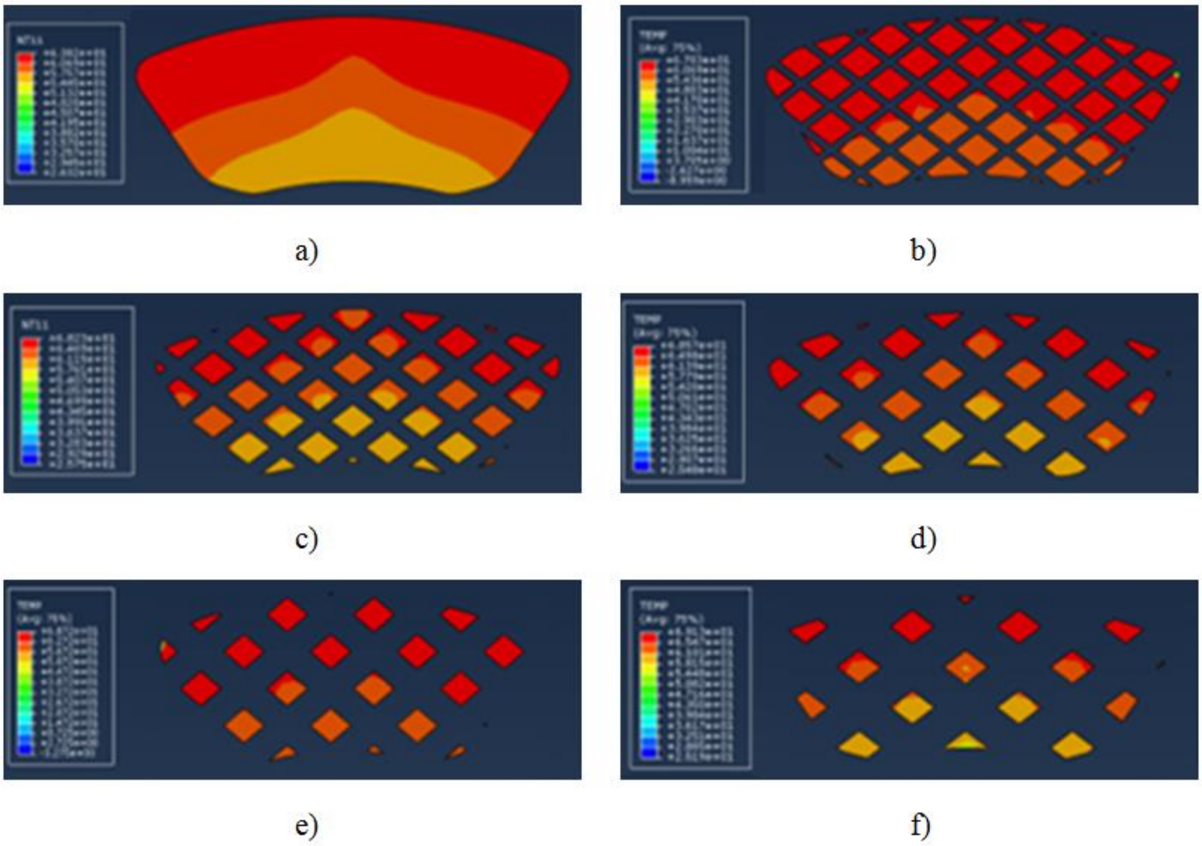

Figure 4. Temperature Distribution on the Brake Adhesive Layer: (a) d=0mm; (b) d=2mm; (c) d=4mm; (d) d=6mm; (e) d=8mm; (f); d=10mm.

The temperature distribution on the brake adhesive layer is comparatively gentle as shown in Figure 4. The maximum temperatures on the adhesive layers are 63.82 ℃, 67.03 ℃, 68.23 ℃, 68.57 ℃, 68.72 ℃ and 69.13 ℃, respectively.

The maximum temperatures are all lower than 80 ℃ -working temperature of adhesive layer. That is why the heat capacity of the brake friction pad is lower than brake rotary plate so the most of the heat is transferred to the rotary plate.

The maximum temperature on the adhesive layer is obtained at 6.2s, 6.5s, 6.7s, 7.0s and 8.8s, respectively.

The maximum temperature on the adhesive layer is obtained slower than on the brake friction surface.

3.2. Stress Analysis

During the braking, the brake adhesive is subjected to thermal as well as purely mechanical actions, and therefore thermal stresses are produced.

The values of thermal stresses in both braking methods are obtained by simulation.

Figure 5 shows the stress distribution in 6 kinds of adhesive layer.

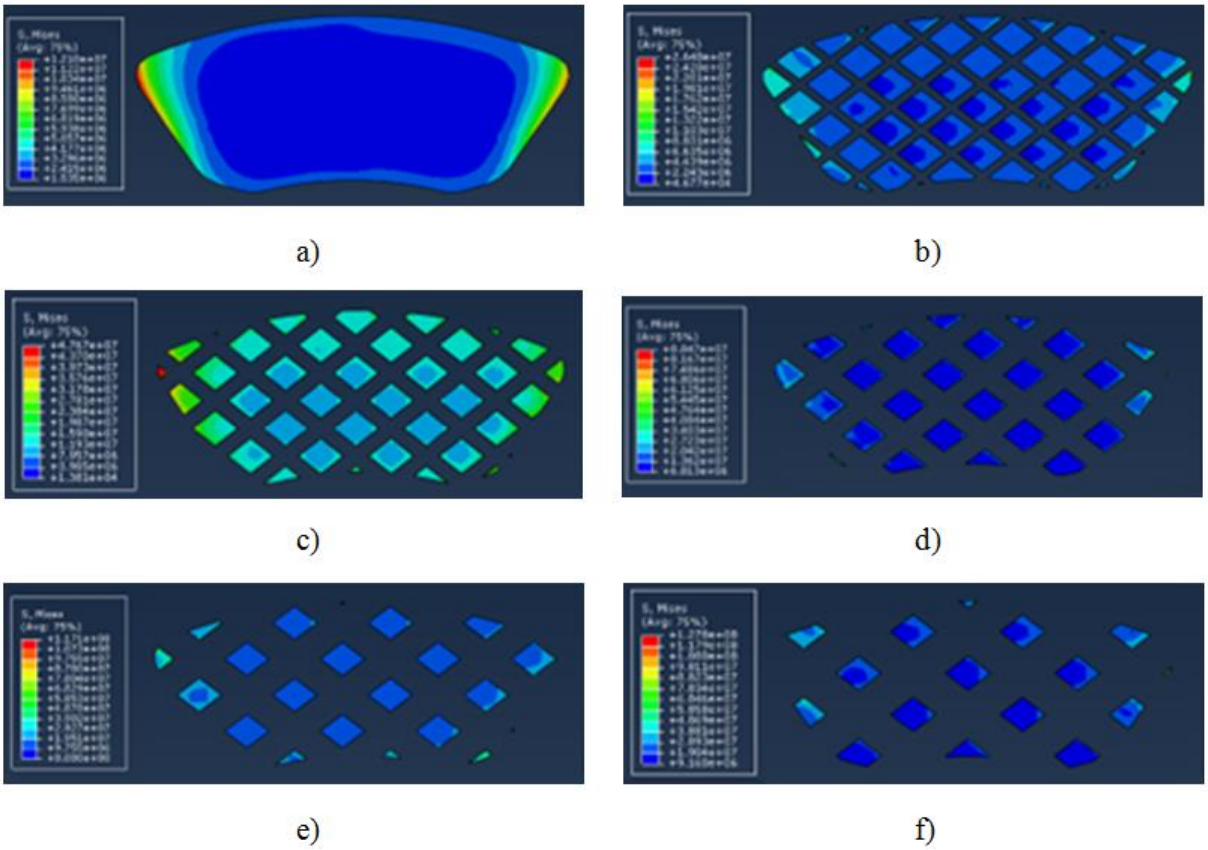

Figure 5*. Mises Stress Distribution in Brake Adhesive Layer: (a) d=0mm; (b) d=2mm; (c) d=4mm; (d) d=6mm; (e) d=8mm; (f) d=10mm.*

As shown in Figure 5, the values of maximum Mises stress are 12.1 MPa, 26.4 MPa, 47.6 MPa, 88.5 MPa, 117 MPa and 128 MPa, respectively.

Stress value increases with the increase of d value. That's because the contact area decreases with increasing space and therefore the stress value of the adhesive layer increases.

In the cases of d=6mm, 8mm, and 10mm, the Mises stress values are higher than the tensile strength value of Araldite 60 MPa, so in these cases, the fracture of adhesive layer can happen during the braking.

4. Conclusion

Thermal-stress analysis was performed under different braking conditions for 6 design parameters of braking pad adhesive layer using ABAQUS 6.14, a finite element analysis program.

Simulation analysis shows that thermal and stress states are different according to the coating pattern of the adhesive layer and its type should be chosen properly according to the thermal and stress conditions.

In all cases, the maximum temperature is below the working temperature.

Simulation shows the stress values at 6mm, 8mm and 10mm spacing between the coating patterns are 88.5 MPa, 117 MPa and 128 MPa so those exceeded the tensile strength value of adhesives.

For d=4mm, the Mises stress value is 47.6MPa and it does not exceed the tensile strength value so it can ensure the working stability.

The adhesives of about 60% are saved.

Abbreviations

FEA	Finite Element Analysis
C/C-SiC	Carbon and Silicon Carbide Composite

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Conflicts of Interest

The authors declare no conflicts of interest.

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