Thermal analysis of composite disc-brake based on finite element method

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Abstract. Disc-brake is designed to decelerate the vehicle by sliding friction between the contact surface of the pad and the disc. This braking process will convert the mechanical energy of the vehicle to the heat energy. In the present paper, based on finite element method, the thermal behaviour characteristic induced by heat energy due to the contact between the pad and the brake surface is investigated varying the rotational velocities. The results show that the highest value of thermal distribution on the second surface of the disc and pad occurs during a high rotational speed. The rated thermal distribution on the surface of the disc is higher than the surface with the pad.

1. Introduction
The brake system as a part of the motorcycle safety system has an important role in protecting the passengers and driver. However, one big issue of the use of disc brakes is temperature rise due to long repetitive braking. The increase in the temperature during braking leads to the decrease in the performance of the brake system. Related to thermal characteristics during braking, some workers have conducted investigations to this issue.

Adamowicz and Grzes[1] based on fully three-dimensional finite element model evaluated an impact of convective mode of heat transfer on the thermal behavior of a disc brake system during repetitive braking process with the constant velocity. It was found that during single braking the convective cooling has insignificant effect on the temperature distributions of a disc brake, consequently is not able to prevent overheat problem. Yevtushenko and Grzes[2] used a finite element analysis to investigate transient temperature fields using the three dimensional contact model of a disc brake focusing on temperature coefficient of friction. In their case, the temperature fields, braking distances, and braking times were calculated and confronted with the cases at the constant coefficient of friction. Grzes et al. [3] conducted the analysis of a temperature field at single braking in a pad-disc braking system of a railway vehicle experimentally as well as numerically. Their main result was that at single braking the disc is not heated uniformly within the depth until the moment of standstill. With respect to the thermal characteristic, Arifin et al. [4], investigated the effect of the presence of ventilation as well as the hole number of the temperature distribution during brake. It was found that the larger the number of the ventilation holes, the lower the maximum temperature variation. In recent lubrication, Nong et al. [5] conducted thermal and thermal stress investigations considering air cooling during emergency braking phase using finite element (FE) and computational fluid dynamics (CFD) methods. It was shown that low temperature was obtained, as well as distributed uniformly on the
brake disc, which attributes to high thermal conductivity of the disc material together with excellent cooling ability of the brake disc.

Based on the literature survey above, it is highlighted that most of the previously published works the pad geometry is not modeled in computational domain. While considering this scientific context, the main objective of the present paper is to investigate the temperature distribution of disc brake induced by the contacting surface using a finite element analysis by modeling the pad geometry. In this way, the heating due to friction between contact between the pad and the disc can be explored, and thus more realistic results can be obtained.

2. Methodology
The procedures for the disc brake simulation were carried out in two stages; the first stage focused on the disc pad operating in steady state and the second stage included operating in moving condition varying the rotational speeds of the disc. The measurement of the temperature of the pad against the disc and the rotation speed of the disc in ABAQUS can be determined through a load module.

For solving the problems dealing with the previousley mentioned stages above, several steps were performed in this study. The first step was to prepare a structure FEM model of the brake disc with pads including types of material used. This step was carried out using finite element software ABAQUS. Then, the boundary condition as well as the loading is applied on the components. The meshing conducted here used automatic feature in ABAQUS to obtain the best configuration of mesh. For final step, the initialization as the assignment of an initial value for a data object or variable was conducted. The manner in which initialization is performed depends on kind of steps as mentioned earlier.

2.1. FEM model
Figure 1 shows the geometric model of the disc brakes of motorcycle. The disc brakes consist of two main components; namely the disc and the brake pad. In the following computation, the contact between the disc and the brake pad occurs due to the applied load. This will generate the friction leading to the occurrence of thermal profile.

![Figure 1](image)

**Figure 1.** Geometry modelling of disc brake with pad of motorcycle

2.2. Material
The material used in the disc brake models consisted of two types, i.e. composite for pad component and stainless steel for disc component. The properties of the two materials in detail are shown in Table 1.
Table 1. Thermal Properties of Composite Materials and Steel

| Materials          | Pad       | Disc       |
|--------------------|-----------|------------|
| Density [kg/m³]    | 1450      | 7,800      |
| Modulus Elasticity [GPa] | 2.2    | 209        |
| Poisson’s ratio    | 0.24      | 0.29       |
| Thermal Expansion [1/C] | 1.1 x 10⁻⁵| 1.26 x 10⁻⁵|
| Thermal Conductivity | 1.1       | 48         |
| Specific Heat [J/kgK] | 1200     | 452        |

2.3. Boundary condition and loading

Figure 2 shows the position of the loading and boundary conditions as applied to a series of disc brakes. Pressure is applied to the outer surface of the second pad, while the boundary conditions were applied to the four pin holes. The pressure applied to the outer surface of the second pad is 1 MPa. The boundary conditions were applied by assuming that the four pin holes cannot move in the direction of x, y and z, but can rotate on the rotary axis z. Rotating speed are varied in three conditions, namely low speed of 120 rad/s, medium speed of 150 rad/s and highest of 200 rad/s.

![Figure 2. Boundary conditions and loading](image)

2.4. Meshing

Figure 3 shows the mesh as applied to this model. The kind of element used was the C3D8T type in which the element type consisted of 8-nodes capable of thermal analysis due to friction and displacement in three directions. The total nodal applied to this model was about 22,195, while the number of elements was around 30,178.
3. Results and Discussion

3.1. On the stationary condition

Figure 4 shows the thermal distribution on the contact surface between the pad and the disc when the disc is not moving. There are two thermal distributions on both sides of the surface, while the pad is only on one side of the contact surface. The maximum thermal value on the disc surface is larger than that on the side with the pad. It indicates that a rise in surface temperature due to the interaction of contact and friction is highlighted.

It is also found from Fig. 4 that the thermal profile is relatively low during stationary condition even there is contact between the pad and the disc. This is as expected because there is no high friction between them. As a note, the brightness of the contour colour in Fig. 4 can be seen on the surface of the disc and pad, where the red colour indicates a high value while the blue colour indicates a low value. The relationship value and colour can be seen in the legend next to the picture of the disc and pad.

3.2. On the moving condition

Figure 5 shows a comparison of the values of the thermal distribution on the contact surface of the disc as a result of contact interaction between the pad and the disc while spinning. This condition is based on spinning the disc at varying speeds. Of the three variations of speed, it can be seen that the value of the highest thermal distribution occurs during high speed. The thermal distribution value here means a rise in surface temperature due to the interaction of contact and friction.
Figure 5. Thermal distribution on the disc during rotational movement, (a) low speed, (b) normal speed, (d) high speed

Figure 6 shows a comparison of the value of the thermal distribution on the contact surface due to the interaction of contact between the pad and the disc during the condition of movement. Figure 10 (a) shows the thermal contact distribution on the pad surface when the disc rotates at a low speed, Figure 10 (b) at the time of medium speed, and Figure 10 (c) at high speed. Of the three variations of speed, it can be seen that the value with the highest thermal distribution occurs at high speed. This is similar to thermal distribution value that occurs on the disc component.

Figure 6. Thermal distribution on the pad when the system is moving, (a) low speed, (b) moderate speed, (c) high speed

Figure 7 shows the comparison of the maximum temperature values on the surfaces of the disc and pad while the disc is spinning. In this case, the disc rotational velocity ranges from slow, medium, and high. Based on Fig. 2, it can be seen that the highest value of temperature distribution on the second surface of the disc and pad occurs during a high rotational speed. It is also found that the rated temperature distribution on the surface of the disc is higher than the surface with the pad. On the other words, it can also be concluded that the higher the speed, the higher the temperature distribution.
Figure 7. Comparison of the temperature distribution between the disc and pad at varying speeds.

4. Conclusion
The main objective of the investigation was to investigate the thermal characteristic of the disc brake induced by the contact with composite pad due to braking. A numerical simulation in steady state was performed using finite element method based software ABAQUS. Based on the explanation above, the conclusions can be drawn as follows:

1. Rotating velocity has a significant effect on the thermal behaviour of disc brake resulted during the braking. It was found that the higher the velocity, the higher the temperature distribution.
2. The highest value of thermal distribution on the second surface of the disc and pad occurs during a high rotational speed.
3. The temperature distribution on the surface of the disc is higher than the surface with the pad.

These findings are useful for the study of the performance of the composite pad-disc brake with respect to the temperature rise during the braking.

References
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