Investigation of Stress, Deformation, and Cracks in the Brakes of Car Using Finite Element Method

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Abstract. Twisting forces in disc brakes and friction forces between disc brakes and bearings produce heat on the disc brakes. The compression force produced by the brake piston pushes the brake pads to produce heat and deformation in the disc brakes. For the development of vehicle braking systems, wrought iron is used to make disks. However, a failure still occurs during a crack testing. The results of the analysis using the finite element method showed that the highest total deformation was $4.411 \times 10^5$ mm. The highest maximum equivalent stress (represented by the red area) is 715.48 MPa. The maximum value of SIFS (K1) around the disc brake hole is $-0.9030 \text{ MPa.m}^{0.5}$, while at the edge of the disc is $5.385 \text{ MPa.m}^{0.5}$.

Keywords: Stress, deformation, crack, brake, FEM

1. Introduction

A car is certainly equipped with a braking system, which is a component that can ensure safety during driving. The braking system, therefore, becomes a vital element in a vehicle. A disc brake is a type of braking system that utilizes additional components, i.e. a disc clamped with two pieces of brake pads serving to slow down or stop the rotation of the wheel. Some studies on disc brakes have been conducted to measure brake torque and shaft speed during braking. Also, theoretical analysis and mechanical systems have been developed and solved numerically using finite-difference methods and Matlab software [1].

Disc brakes are commonly made of cast iron. Cast iron is preferred for producing disc brakes because of its economic advantage, ease of manufacture, strength, and resistance to temperature. The cast iron is composed of Ni, Cr, and Mo. The strength of cast iron is influenced by the intermetallic phases formed during solidification of the alloy. The compositional variations of wear track indicate higher oxygen content of tribo-layer. This may be due to the presence of elemental oxides (such as Al, Si, Cu, Sn, and Fe) in the test materials [2]. This chemical content is predetermined through research. Along with the advancement of technology, the demand for disc brakes with greater strength and resistance to temperature is enormous and accelerating exponentially. In addition to strength and resistance to temperature, the weight of the disc brake is also a key consideration. Moreover, the ability of each brake to absorb energy should be improved [3]. Wrought iron which consists only of carbon steel is used for resistance to friction. Cracking is one of the main problems encountered during the operation of disc
brake parts. One way to extend component life is by developing new materials [4]. An example of the cracking on the disk brake can be seen in Figure 1.

During the braking process, wet disc brakes can withstand excessive wear, high temperature, and thermal elastic deformation, which results in deterioration of braking or stability that affects passenger comfort and shortens the life of disc brakes [5]. Simulation analysis of disc brakes is needed to determine the effect of damage caused by friction forces and compressive forces which results in thermal deformation in disc brakes. In an industrial context, Eigenvalue Complex Analysis (CEA) has been widely used to detect instability and to predict the tendency of disks to scream. To date, most numerical simulations have shown a dominant influence of the pad-disk interface on the stability of the brake system [6]. The simulation in this paper aims to find the deformation, stress, and cracks that occur in the disc brake. The pressure on the disc brake will cause cracks. The results will be aimed at making the industry more considerate of materials, design, and construction in making disc brakes. A good material will give maximum rigidity or produce good quality.

Figure 1. Cracking on the disc brake.

2. Methods
In the analysis, the finite element method (FEM) was used to calculate the stress on the disc brake. The disc brake was designed using the numerical simulation—a cost-effective method for a low-budget production. The finite element analysis offers a method of conducting easy and efficient research on various parameters used with design and manufacturing conditions that are easily evaluated. The forces occurring in the disc brake was caused by the disc brake system. One of the forces, the compression force, was generated by the brake piston pushing the brake pads and resulting friction. The friction force between the brake disc and pads produced heat or thermal energy in the disc. Moreover, the rotating disc caused a twisting force [7]. In the disc brake, there were some frictional forces on the surface of the rotating disc and on the internal surface of the rotating drum [8]. The friction could occur due to the contact between the brake pads and disc [9]. The disc brake was designed using software called Autodesk Inventor with dimensions of a regular disc brake for a four-cylinder engine. The disc brake was made of wrought iron. Material properties above is a material number that is used in this study. This figure is the value of the wrought iron in this analysis.

| Material Property          | Value     | Unit   |
|----------------------------|-----------|--------|
| Density                    | 7.7       | g/cm³  |
| Young’s Modulus            | 193100    | MPa    |
| Poisson’s Ratio            | 0.278     |        |
| Yield Strength             | 159-221   | MPa    |
| Ultimate Tensile Strength  | 234-372   | MPa    |
A simulation was performed on the disc brake to determine its strength using ANSYS Workbench 15 because this software can analyze accurately[15]. The disc brake was subjected to various loading conditions during the simulation. The simulation results showed the stress and deformation of the disc brake under maximum loading conditions. The results were analyzed and become the basis for conducting crack analysis on the disc brake rotor, as it had cracked. In the crack test, cracks were found in areas surrounding the disc brake holes. The crack dimensions included: 8 mm (major radius), 5 mm (minor radius), and 5 mm (large contour radius) with a mesh size of 6 mm. Then, a certain amount of force was applied.

3. Results and Discussion

This section presents the outcomes of a simulation done by ANSYS 15.0. The simulation results were analyzed and discussed thoroughly through description and images. The following are the results of von Mises stress, total deformation, principal stresses, and cracks that occur in the disc brake. Figure 2 shows a meshing process of disc brake design. In this process, it will be easily found that how to determine the area that will be subjected on a disk brake. Furthermore, when giving meshing use the 5 mm, it will be analyzed the deformation, stress, principal stress, and cracks.

Figure 3 illustrates the simulation result of maximum stress on the disc brake. As shown in the red area, the highest maximum equivalent stress was 715.48 MPa. The lowest equivalent stress was 79.498 MPa. Mow and Cheng in [10] analyzed the analytical solutions for thermal stresses in half the elastic space and revealed that the dominant thermal stress on the surface near proportional to temperature is between 100 Mpa. The results of the stress analysis in figure 3 are clearly depicted that the stress exceeds the limit.
Figure 4. Deformation of disc brake design.

Figure 5. Maximum principal stress of disc brake design.

Figure 6. Cracks surrounding the holes of disc brake design.

Figure 7. Crack at the edge of the disc of disc brake design.
Figure 4 shows the total deformation of the disc brake. The highest total deformation was $4.411 \times 10^5$ mm. The maximum stress and deformation always occurred at the edge of the disc brake because of the brake pads attaching and pushing on the outside of the disc that this results in excessive deformation because of the permissible size of deformation. Meanwhile, Figure 5 as well as equivalent stress, principal stress is also located at the end of the disc, as it is known that this disc moves in circles and there is friction between disc and canvasses, and results in pressure and heat. The value of this principal stress has a maximum value of around 413 MPa. Furthermore, Figure 6 shows a simulation of a front crack and a simulation of a crack from the side. This illustrates, where the starting point of the crack starts from around the existing hole there is a disc. Cracks will move from the end of the disc to the last hole. This indicates that the crack will continue to move towards the disc.

Figure 7 is similar to Figure 6, if Figure 6 is predicted cracks start from the disc hole, then for Figure 7 the crack is predicted to start from the tip of the disc in contact with the canvas. This crack starts from the tip of the discs and moves towards the discs. The composition of friction material may decrease or increase the corrosion formation on the surface of disc brakes [11], even resulting in cracks. In 2002, Nakatsuji et al. in [12] conducted research on the initiation of hair-like cracks forming around small holes in the flanges of one-piece discs during overloading. In this study, the analysis of crack occurring in the disc brake was conducted by examining the values of J-Integral and SIFS (K1). The J-Integral value is the strain energy release rate of a crack body per unit. The SIFS value is the one used to determine the stress intensity factor (K) of a material with a certain geometry shape under elastic loading conditions. The result of this paper is the maximum value of SIFS around the disc brake holes was -0.9030 MPa.mm$^{0.5}$ while the minimum value was -0.8311 MPa.mm$^{0.5}$. Moreover, the maximum value of SIFS at the edge of the disc was 5.385 MPa.mm$^{0.5}$, while the minimum value was -15.65 MPa.mm$^{0.5}$.

Based on this result, it can be concluded that the greater the value of K1 and reaches the critical value of Kc, the material will be broken due to high voltage intensity, therefore the selection and design of holes in the manufacture of disc brakes need to be considered.

4. Conclusion
The simulation aimed to analyze the thermomechanical behavior of the contact between the brake disc and pads during the braking events. The modeling was done using ANSYS. This suggested that the disc system could generate a good high-temperature resistance. As shown by the analysis results, the temperature and stress field in the braking process. The temperature, stress, and total deformation of the disc and contact pressure of the pads rose due to the additional thermal stresses to the mechanical stresses, causing the cracks to propagate, the bowl to fracture, and the disc and pads to wear off. The highest total deformation was $4.411 \times 10^5$ mm. The highest maximum equivalent stress (represented by the red area) was 715.48 MPa. The maximum value of SIFS around the disc brake holes was -0.9030 MPa.mm$^{0.5}$, while that at the edge of the disc was 5.385 MPa.mm$^{0.5}$.

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