Design Enhancement and Thermal Analysis of Disc Brake

B Roshan Rino, M Pranesh Kumar and S Velmurugan
Mechanical Engineering, Bannari Amman Institute of Technology, Erode, India
roshanrino.me19@bitsathy.ac.in, praneshkumar.me19@bitsathy.ac.in, vsvmurugan@gmail.com.

Abstract. In automobiles, the function of disc brakes is controlled by jamming the brake pads opposed to a rotary disc that is usually attached to a wheel. A composite material set is preferred to manufacture the brake pads. This braking process produces frictional forces which cause deceleration and eventually stops the rotation of the disc. The indulgence of the generated heat due to friction is important for successful braking. Changes in temperature of the brake cause radial and axial bend; this variation in shape, in turn, distresses the proper alignment of the pads and the disc. The aim of this paper is to design a brake disc and perform the thermal stress analysis by applying five different materials namely Gray cast iron (GCI), reinforced Ti-composite (TMC), Ti-alloy (Ti-6Al-4V), reinforced Al-Cu alloy (AMC 2), and reinforced Al-composite (AMC 1). The modelling and analysis of the disc brake are achieved with the aid of SOLIDWORKS and ANSYS software.

1 Introduction
A disc brake is used as calipers to jam the pads set contrary to a disc to create friction, this action reduces the speed of a wheel, either to decrease its rotational speed or to grasp it as motionless. [1,2 &3] The energy of motion is transformed into excess heat which is dispersed into the air. [4,5&6] The disc is designed to be ventilated which allows heat to dissipate more efficiently. When compared to drum brakes disc brakes operates much more efficiently and with better capabilities if dissipating heat. These brakes have applications in the automotive industry for almost all types of vehicles. The increase in production of these types of brakes for commercial purpose was in the year 1955 the same model sold over 1.5 million pieces over the course of 20 years without a single modification being made. The same type of brakes is used in motorcycles, bi-cycles, trucks as well as other heavy automotive vehicles such as train and serves the purpose quite efficiently and no other better options have been yet found. This paper concentrates on the disc brakes which are used in a commercial four-wheeler. A ventilated disc brake model was designed using SOLIDWORKS software and the effects on the model under influence of high temperature was studied for the five materials and the results were compared for all the materials.

2 Properties of materials
Grey cast iron has high thermal conductivity and specific heat capacity as well as good frictional properties this material generally used in disc brakes [7]. Ti-alloy, Ti-6Al-4V, otherwise named as TC4, Ti64, or ASTM Grade 5, is an alpha- beta titanium alloy with a good strength-to-weight ratio and exceptional resistance to corrosion, [8] When compared with steel and nickel-base materials Titanium matrix composites (TMCs) offer stiffness and high specific strength. High temperature TMCs can propose up to 50% weight reduction compared to monolithic superalloys which compensate the strength and stiffness [9&10]. Hardening alluminium metals by adding other elements is common method, one of these methods is to add copper to the metal to greatly increase the hardness of the material currently the most widely used composition is addition of 6.7% of copper. Aluminium metal matrix composites which are reinforced with silicon carbide have much significance as an engineering
material (AMC 1), having high specific strength and stiffness play a major role in situations where the material is expected to last for long durations without any replacement in which saving weight is an important feature [11].

Table 1 shows the physical properties of the selected materials. The conventional material GCI is chosen because of its high frictional coefficient and reasonable specific heat capacity. However, the other materials have similar properties.

| Properties         | Materials | 1               | 2       | 3           | 4          | 5            |
|--------------------|-----------|-----------------|---------|-------------|------------|--------------|
|                    |           | Compressive     | Frictional | Wear Rate   | Specific heat | Specific      |
|                    |           | Strength (Mpa)  | Coefficient | (x10^5mm^3/N/m) | capacity (kJ/kg.K) | gravity (kg/m^3) |
| GCI                | 1253      | 0.41            | 2.35     | 0.46        | 7.2        |
| Ti-6Al-4V          | 1070      | 0.34            | 246.6    | 0.58        | 4.42       |
| TMC                | 1300      | 0.31            | 8.19     | 0.51        | 4.68       |
| AMC 1              | 406       | 0.35            | 3.25     | 0.98        | 2.7        |
| AMC 2              | 751       | 0.44            | 2.91     | 0.92        | 2.8        |

3 Modelling and Analysis

3.1 Modelling

The disk break of the car is designed in solidworks 2020. The disk break is shown in the figures 1&2.
3.2 Analysis

For the purpose of analyzing the models Ansys R2 is used, the solidworks file is imported into IGS format. Equivalent stress and the deformation is calculated for the disk break using different materials Gray cast iron (GCI), reinforced Ti-composite (TMC), Ti-alloy (Ti-6Al-4V), reinforced Al-Cu alloy (AMC 2), and reinforced Al-composite (AMC 1) to find which material is best for disk break. Generally, the maximum temperature a disc brake reaches is from 300°C – 800°C depending upon the maximum speed of the vehicle since the analysis is not for supercars an average temperature of 500°C was used the convection rate was given as “Stagnant air simplified case” after applying these conditions in the next step for static structural analysis a pressure of 2MPa was added on either sides (as shown in figure 3) to simulate the pressure applied by the calipers and the results were obtained as follows [12].

![Figure 2. Drawing of disk](image)
Figure 3. Application of pressure and fixtures
4 Result and Discussion

Figure 4. Equivalent stress (Grey Cast Iron)

Figure 4 shows the equivalent stress that acts upon the disc (Grey Cast Iron) after dissipation of heat and action of pressure from the calipers is found to be a minimum of 0.34 and a maximum of 1547 MPa. We can also observe that the stress levels are highest in the bolt holes due to the fixed geometry. Since Grey Cast Iron is the conventionally used material for these disc brakes these results will be taken as reference for all the other 4 materials.

Figure 5. Equivalent stress (Al-Cu alloy)
Figure 5 shows the equivalent stress that acts upon the disc (Al-Cu alloy) after dissipation of heat and action of pressure from the calipers is found to be a minimum of 0.715 and a maximum of 2358 MPa. We can also observe that the stress levels are highest in the bolt holes due to the fixed geometry. The stress level of Al-cu alloy is higher when compared to Grey Cast Iron as well as all other materials taken for this study therefore this material is least good at handling stress.

![Figure 5. Equivalent stress (Al-Cu alloy)](image.png)

**Figure 5.** Equivalent stress (Al-Cu alloy)

Figure 6 shows the equivalent stress that acts upon the disc (Ti alloy) after dissipation of heat and action of pressure from the calipers is found to be a minimum of 0.343 and a maximum of 1152 MPa. We can also observe that the stress levels are highest in the bolt holes due to the fixed geometry. Here the stress level is reasonable when compared to all other materials it has lower stress than Grey Cast Iron only the metal matrix materials have better results.

![Figure 6. Equivalent stress (Ti alloy)](image.png)

**Figure 6.** Equivalent stress (Ti alloy)

Figure 7 shows the equivalent stress that acts upon the disc (Ti-composite) after dissipation of heat and action of pressure from the calipers is found to be a minimum of 3.402e-3 MPa and a maximum of 151.78 MPa. We can also observe that the stress levels are highest in the bolt holes due to the fixed geometry.

![Figure 7. Equivalent stress (Ti-composite)](image.png)

**Figure 7.** Equivalent stress (Ti-composite)
Figure 7 shows the equivalent stress that acts upon the disc (Ti-composite) after dissipation of heat and action of pressure from the calipers is found to be a minimum of $4.2 \times 10^{-5}$ and a maximum of 131 MPa. We can also observe that the stress levels are highest in the bolt holes due to the fixed geometry. The Titanium is the second best at handling stress. It can handle stress much better than the conventional material Grey Cast Iron.

![Figure 7. Equivalent stress (Ti composite)](image)

Figure 8 shows the equivalent stress that acts upon the disc (Al composite) after dissipation of heat and action of pressure from the calipers is found to be a minimum of $5.2 \times 10^{-5}$ and a maximum of 123 MPa. We can also observe that the stress levels are highest in the bolt holes due to the fixed geometry. The aluminium metal matrix material has the lowest stress level among the five chosen materials it significantly lower than the conventional material that is GCI. Therefore as far as thermal stress is concerned Al composite is the best material.

![Figure 8. Equivalent stress (Al composite)](image)
Figure 9. Deformation (Grey Cast Iron)

Figure 9 shows the deformation suffered by the disc when material Grey Cast Iron was added and subjected to condition mentioned above the values given are the total deformation in mm. the minimum deformations value is 0 and the maximum deformation is 0.47. The deformation occurs more at the outer edges of the disc due to the pressure from the calipers. The deformation of Grey Cast Iron for reference to compare with other chosen materials.

Figure 10. Deformation (Al-Cu alloy)
Figure 10 shows the deformation suffered by the disc when material Al-Cu alloy was added and subjected to condition mentioned above the values given are the total deformation in mm. The minimum deformations value is 0 and the maximum deformation is 0.995. The deformation occurs more at the outer edges of the disc due to the pressure from the calipers. The deformation of this material is much better than the compared with the matrix materials however when compared to the conventional GCI its deformation is greater.

![Figure 10](image)

**Figure 10. Deformation (Al-Cu alloy)**

Figure 11 shows the deformation suffered by the disc when material Ti alloy was added and subjected to condition mentioned above the values given are the total deformation in mm. The minimum deformations value is 0 and the maximum deformation is 0.406. The deformation occurs more at the outer edges of the disc due to the pressure from the calipers. The deformations occurring when this material is the least among the 5 chosen materials therefore this material could be a good alternative for GCI.

![Figure 11](image)

**Figure 11. Deformation (Ti alloy)**
Figure 12 shows the deformation suffered by the disc when material Ti-composite was added and subjected to condition mentioned above the values given are the total deformation in mm. the minimum deformations value is 0 and the maximum deformation is 3.2. The deformation occurs more at the outer edges of the disc due to the pressure from the calipers. This material deforms much greater than GCI which would suggest that this material is not a proper replacement for Grey Cast Iron.

Figure 13. Deformation (Al composite)
Figure 13 shows the deformation suffered by the disc when material Al composite was added and subjected to condition mentioned above the values given are the total deformation in mm. the minimum deformations value is 0 and the maximum deformation is 3.9. The deformation occurs more at the outer edges of the disc due to the pressure from the calipers. Both the metal matrix composites have significantly higher deformation when compared to all the other materials.

After the analysis process was complete the results were put into 2 graphs for the purpose of easier comparison one of the graphs compares the maximum stress suffered by each material and the other compares the maximum deformation suffered by each of the chosen material

![Graph showing maximum stress vs material](image)

**Material**

Figure 14. Comparison of Maximum stress

The Figure 14 shows the maximum stress suffered by each material when subject to functioning conditions. Here it is observed that aluminium composite and titanium composite and aluminium has the lowest stress titanium alloy is the next best thing and Grey Cast Iron also has some reasonable levels of stress.
The Figure 15 shows the maximum deformation of the disc when subjected to functioning conditions. It is observed that the materials which suffer the least amount of deformation are both Grey Cast Iron and Titanium alloy.

5 Conclusion
From the above graphs and figures we can observe that both Titanium alloy and GCI (Grey Cast Iron) show significantly better results than the other materials. Grey Cast Iron deforms only 0.5 mm at the given conditions and titanium alloy deforms nearly 0.4 mm which is less when compared to the other selected materials which have over 3mm of deformation. When it comes to stress levels it is observed that both the metal matrix materials have significantly lower stress level below 500 MPa whereas both Grey Cast Iron and Titanium alloy have stress levels ranging from 1000 to 1500 MPa, however when both stress and deformation is taken into consideration only GCI and Titanium alloy seem to be a viable option from this, we can conclude that both titanium alloy and Grey Cast Iron can be used effectively for disc brakes.

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