

## Thermal Analysis of Disc Brake using Ansys Software

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**Abstract**-The objective of this study is to analysis the thermal behaviour of the non-vented (solid) disc using ANSYS software. The Reliable and effectual braking is an imperative requirement of safe transportation. The disk brake generally has a high braking ratio and alleviates the thermal load of the wheels, therefore it has been extensively used in vehicles. Disk brakes are persistently showing to large thermal stresses during routine braking and are subject to unexpected temperature distribution during hard braking. In this study solid disc brake rotor of vehicle has been taken in investigation which is made of martensitic stainless steel and Ceramic material. These materials have been selected to improve the braking efficiency and provide better stability to the vehicle. The modelling of disc brake rotor is done using solid works and the thermal analysis of disc brake rotor has done using ANSYS software (ANSYS 15). ANSYS software has been used for determining the variation of the temperature and heat flux across the disc brake profile. A comparisnal study has been made between two different materials used for solid type disc brake and the best material for making disc brake have been suggested on the basis of magnitude of temperature distribution and total heat flux. The computational results are presented for the temperature distribution and heat flux on each friction surface between the disc and pad. After the investigation result of temperature distribution and heat flux of the Ceramic material was found excellent.

**Keywords:** Solid works, ANSYS 15, Thermal analysis

### I. Introduction

Reliable and effective braking is an important prerequisite of safe transportation. The disc brake is an important part of the vehicle. A brake is a device which provides frictional resistance to the moving bodies, in order to stop the motion of vehicles. The disk brake usually has a high braking ratio and alleviates the thermal load of the wheels so effectively that it has been widely used in vehicles. Disk brakes are constantly exposed to large thermal stresses during routine braking and are subject to extraordinary thermal stress during hard braking (Mackin *et al.*, 2002).

The Disc brake was started in England in the 1890s for use. The first caliper type automobile car disc brake was designed by Frederick William Lanchester in his Birmingham factory in 1902 and used effectively on Lanchester cars. Compare to drum brakes, disc offer better stopping operation, because the disc is more promptly cooled (Tiwari *et al.*, 2014). However, due to limited availability of metals the cast iron and copper were used for braking medium of the vehicles. Dust, stony and rough tracks were resulting into quick wearing of cast iron and cooper. Hence, the disc brake was a non viable system. It took another half century for his innovation to be adopted world extensively.

In practice, there are two types of disks, including the non-vented (solid) type disk and ventilated disk. The disc brake is a device for stopping the rotation of a wheel (Sarkar and Rathod, 2013). The disc brake is connected with the wheel and/or the axle. Brake pads which are mounted on brake calliper, made by friction material and used to stop the wheel. A typical automotive disk brake is illustrated in Fig. 1.

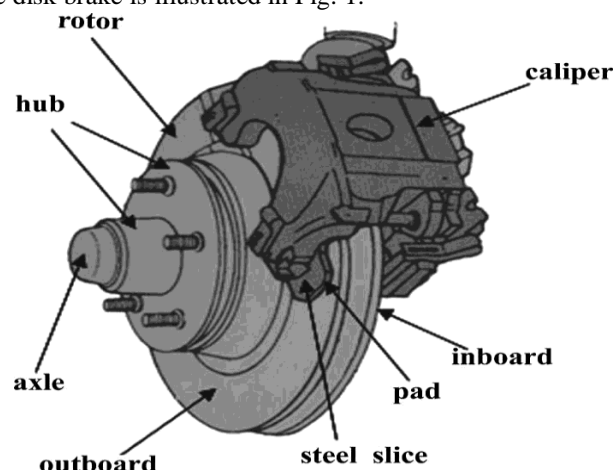


Fig. 1 Non-vented (Solid) disc brake

The main components of the disc brake are:

- i. Brake Pads
- ii. Caliper
- iii. Rotor

**The basic needs of a disc brake system are as follows**

- i. The brakes must be strong enough to stop the vehicle in emergency at minimum distance
- ii. The driver must have proper control over the vehicle during braking
- iii. The brakes should have an excellent anti wear properties.

**Application of disc brake**

**1) Transportation**

- i. Emergency Vehicles - Police and Ambulance
- ii. Large Walk-in Delivery Trucks
- iii. Buses - School and People/Shuttle
- iv. SUV (Sports Utility Vehicles), RV, Limo & Pickup Trucks and many small types of vehicles

**2) Industries**

- i. Wind Power Generators
- ii. Conveyors

**1.2 Thermal Analysis**

A thermal analysis calculates the temperature distribution and related thermal quantities in a structure or component. Typical thermal quantities of interest are the temperature distributions, thermal gradients, thermal fluxes and amount of heat lost or gained. Thermal analysis is usually performed to elevate or identify the change in value of material properties to the elevated temperature.

**1.3 Finite element analysis**

The finite element method (FEM) is numerical analysis technique for obtaining approximate solutions to a wide range of engineering problems.

**1.4 Ansys**

ANSYS is a general-purpose of finite element modelling package for numerically solving a wide variety of mechanical problems. Finite Element Analysis (FEM) is a numerical method of deconstructing a complex structure into very small pieces called elements. The ANSYS software has many finite element analysis capabilities, with the range from a simple, linear, static analysis to a complex, nonlinear, dynamic analysis (Narayana *et al.*, 2012).

**II. Review of Literature**

**Lee and Barbar [4]** investigated the Effect of Intermittent Contact on the Stability of Thermo elastic Contact, the frictional heat generated during braking causes thermo elastic distortion that modified the contact pressure distribution. When the sliding speed was sufficiently high, that could lead to frictionally excited thermo elastic instability (TEI), characterized by main non-uniformities in pressure and temperature. In automotive applications, a particular area of concerned the relation between thermo elastically induced hot spots in the brake discs and noise and vibration in the brake system.

**Gao *et al.*[2]** observed the Stress Analysis of Thermal Fatigue Fracture of Brake Discs Based on Thermo mechanical Coupling and developed a three dimensional thermal-structure coupling model, implemented transient stress analysis of thermoelastic contact of disc brakes with a frictional heat variation and identified the source of the thermal fatigue. The transient thermoelastic analysis of disc brakes in an emergency brake application has been performed. The thermal-structure coupling model was developed and applied to thermoelastic contact with frictional heat generation. The frictional heat flux coupling between the working surface of the disc and the pad was investigated, and the variation of the rotating speed during the braking process been taken to account. The analysis and simulation identified the interaction of frictional heat generation, thermal distortion, and elastic contact made a "hot band" occurred at the working-surface of the disc, which was a precursor of critical hot spotting.

**Thilak *et al.* [5]**, investigated into usage of new materials is required which improve braking efficiency and provide better stability to vehicle. This study can be done using ANSYS software. ANSYS 15.0 is a dedicated finite element package used for determining the temperature distribution, difference of the stresses and deformation across the disc brake profile. In the present work, investigate the suitable hybrid composite material which is lighter than cast iron and has good Young's modulus, Yield strength and density properties. Aluminium base metal matrix composite and high strength glass fibber composites have friction and wear manners as a Disk brake rotor. The transient thermo elastic analysis of Disc brakes in repetitive brake applications has been performed and the results were compared. The suitable (proper) material for the braking operation is S2 glass fibber and all the values obtained from the analysis are less than their allowable values. Therefore the design of brake Disc is safe based on the strength and rigidity criteria. By identifying the correct design features, the extended service life and long time stability is assured.

**Babukanth and Teja [6]** studied transient analysis of disc brake using ansys software. Due to the application of brakes on the car disc brake rotor, heat generation takes place due to friction and this thermal flux had been conducted and spread

across the disc rotor cross section. The condition of braking was very much severe and thus the thermal analysis been carried out.

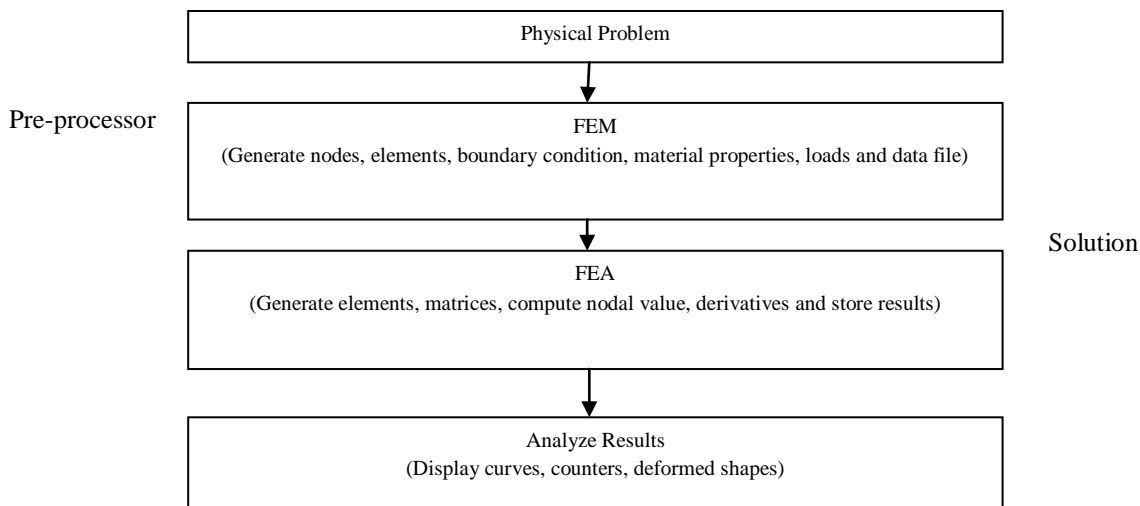
**Shahzamanian et al. [8]** investigated the finite element contact analysis of a functionally graded (FG) brake disk in contact with a pad, subjected to rotation, contact pressure, and frictional heat, is presented. The material properties fluctuate through the thickness according to a power law characterized by a grading index,  $n$ . The contact surfaces of disc brake are full ceramic with full-metal free surface. The effects of  $n$  on the displacement, contact status, strain and stress are investigated. From the analysis, thermoelastic and contact results are exceedingly dependent on  $n$ . Hence,  $n$  is an essential criteria for the design of FG brake disks for automotive and aircraft applications.

### III. Materials and Methodology

In this study ceramic material (material for analysis) has used. The ceramic material has good mechanical properties. The strength of ceramic material with unidirectional reinforcement fibres is up to 700 MPa. Ceramic materials retain their properties above 2000 °C<sup>5</sup>. This temperature may be further exceeded with the help of protective coatings to prevent oxidation. The material has a density between 1.6–1.98 g/cm<sup>3</sup>. The Ceramic material has high fracture toughness or crack resistance capacity. Ceramic or reinforced materials are inorganic, non-metallic materials made from compounds of metal and non-metal. Ceramic composite may be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling.

For the analysis of disc brake using ansys software involves this three phases

- i. Pre-processor phase
- ii. Solution phase
- iii. Post-processor phase



Postprocessor

**Procedure of analysis:** The procedure for static and dynamic analysis has been carried out under the following steps

- i. Develop the model
- ii. Generation the solution
- iii. Analysis the results

**Development of model:** In this step we specified the job name and analysis title use PREP7 (these commands are used read model data into the database, list out the database, and control the numbering of entities in the database). This analysis defines the element types, element real constants, material properties and model geometry element type both linear and non- linear structural elements are allowed. The ANSYS elements library contains 100 different element types. A unique number and prefix identify each element type. Some element type is described as follows.

E.g. BEAM 188, PLANE 183, SOLID 96 and PIPE 16

Input parameters involved into the study of both the materials viz. martensitic stainless steel and ceramic have been shown into the **table 2** and **table 4** respectively. Since the essential properties such as Young's modulus (EX), thermal conductivity (KXX) and expansion coefficient (ALPX), temperature etc. have to be defined in advance for static and dynamic analysis, therefore load has been applied under different operating conditions such as varying angular velocity and hydraulic pressure [13].

**Table 1: Mechanical properties of CA-15 (Martensitic stainless steel)**

CA-15	
Heat treatment	Tempering at 750°C, air cooling
Ultimate tensile strength $\sigma_b \geq$	560 Mpa

Yield strength $\sigma_{s \geq}$	400 Mpa
Elongation $\sigma_{\delta \geq \%}$	
Endurance limit $\sigma_{-1 \geq}$	246 Mpa

**Table 2:** Material properties of CA-15 (Martensitic stainless steel) for disc and resin-bonded composite frictional material for pad

Properties	Disc	Pad
*Thermal conductivity, k (W/mk)	48.46	1.212
Mass density, $\rho$ (kg/m <sup>3</sup> )	7228	2595
Specific heat, c (J/kgK)	419	1465
Thermal expansion coefficient, $\alpha$ (1/k)	$11 \times 10^{-6}$	$30 \times 10^{-6}$
Elastic modulus, E (GPa)	175	1.5
Poisson's ratio, $\nu$	0.3	0.25
<b>Operating conditions</b>		
Angular velocity, $\omega$ (rad/s)	88.46	-
Hydraulic pressure, P (Mpa)	3.17	-

**Table 3:** Structure parameters of the disc and pad

Parameters	Disc assembly	
	Disc	Pad
Inner radius (mm)	32.5	77
Outer radius (mm)	128	125
Thickness (mm)	12.5	14.3
Cover angle ( $\theta$ ) of pad	64.5	-

In regards of material selection, as many researchers<sup>2,8-10</sup> Gao *et al.*, Shahzamanian *et al.*, Belhocine *et al.*, and Gowrisankar *et al.*, have done research on Martensitic

stainless steel as disc brake and they found that Martensitic stainless steel has good yield strength (about 400 MPa). It can sustain high braking stress and also bear the temperature up to 750°C. Due to compatible properties of Martensitic stainless steel is stable for disc brake; therefore it is widely used in automobile sectors.

The analysis of disc type cluster of martensitic stainless steel for normal (non-vented) disc has already been done by Gao *et al.*<sup>2</sup>. Similarly analysis with martensitic stainless steel has been performed here to validate the procedure. Thereafter structure and thermal analysis under static and dynamic condition for non-vented disc is performed with the martensitic stainless steel. The above analysing has been done to assess the different results (deformation, stress and strain) along with martensitic stainless steel (structural steel) on solid disc.

**Table 4:** Various material properties of the partially stabilized Zirconia (PSZ), ceramic material for disc and pad

Properties	Disc and Pad
Thermal conductivity, k (W/mk)	2
Mass density, $\rho$ (kg/m <sup>3</sup> )	5700
Specific heat, c (J/kgK)	400
Thermal expansion coefficient, $\alpha$ (1/k)	$10 \times 10^{-6}$
Elastic modulus, E (GPa)	151
Poisson's ratio, $\nu$	0.3
Coefficient of friction, $\mu$	0.75
<b>Operating conditions</b>	
Angular velocity, $\omega$ (rad/s)	88.46
Hydraulic pressure, P (Mpa)	3.17

#### IV Result and Discussion

This chapter deals with the results found after the analysis of disc brake using ANSYS software. In this chapter the results of temperature distribution of disc with Martensitic stainless steel for non-vented condition is compared with the

results found by Gao *et al.*, 2007 to validate the procedure. Thereafter two disc assembly, disc assembly made of different materials (Martensitic stainless steel and Ceramic material) are compared with non-vented (normal) condition.

#### 4.1 Validation and analysis of non-vented disc assembly with Martensitic stainless steel

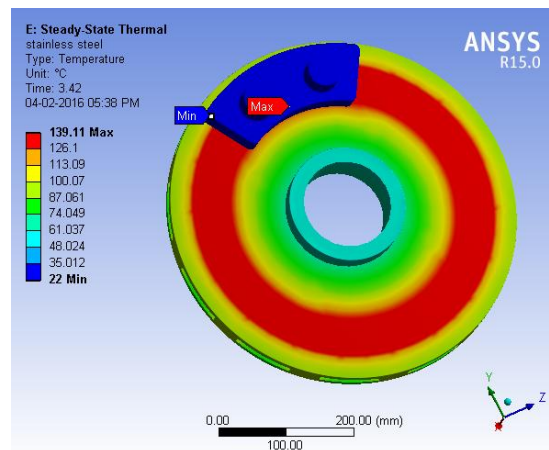
##### 4.1.1 Temperature and Total Heat Flux Distribution

In the disc brake system many problems like distortion, hot spot and cracks are occurred at the working surface of the disc. These problems occurred due to temperature distribution in the disc, which generated by the friction heating between disc and pad. Figure 4.1 and Figure 4.2 display the temperature and heat flux distribution of non-vented disc brake made of Martensitic stainless steel. In the initial stage of braking, due to the high rotating velocity of the disk heat flux generated. Due to heat generation in disc, temperature on disc is high. The temperature on the non-contact region of the disk is almost constant due to no frictional heat generation in that region. Thus, the great compressive stress is generated in the contact region and the tensile stress is produced in other parts (non-contact region).

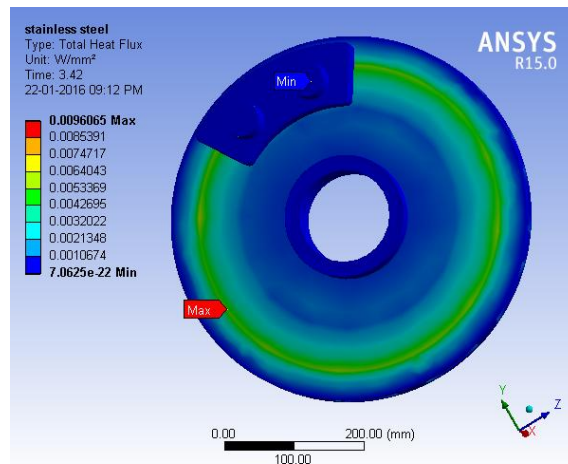
It has been observed that the temperature of the disc varies in the range of 22 °C to 139.11 °C. The maximum temperature distribution in the disc represented by red colour with the range 126.10 °C to 139.11 °C and minimum temperature distribution represented by blue colour with the range 22 °C to 35.012 °C. In the Fig. 4.2 shows the maximum heat flux by red colour with the range from 0.0085391 W/mm<sup>2</sup> to 0.0096065 W/mm<sup>2</sup> while green colour shows intermediate heat flux with the range from 0.0042695 W/mm<sup>2</sup> to 0.0053369 W/mm<sup>2</sup>. These temperature and heat flux distribution is observed for 3.42 sec. The running condition of the disc is 88.46 rad/s and the hydraulic pressure on the disc is 3.17 Mpa. This is the normal running condition and pressure of the disc brake was taken by many researchers like Gao *et al.*, 2007, Thilak *et al.*, 2011 and Narayana *et al.*, 2012.

Gao *et al.*, 2007 have also performed similar kind of study using ANSYS software. They have taken different parameters shown in Table 4.3. This parameter is standard parameter of disc and pad. Gao *et al.*, 2007 have also reported that the temperature distribution in the range of 0.261°C to 138.77 °C. Therefore, it can be presumed that the procedure adopted for the analysis of clutch disc assembly is correct and have validate our analysis procedure.

The similar work was done by Thilak *et al.*, 2011 using cast iron and E-Glass (reinforcement material). They have reported the temperature as 486.76 °C and 1219.8 °C respectively. The hot spot, distortion and cracks were occurred on the disc which is due to the material properties of both material (cast iron and E-glass). The material properties of cast iron e.g. modulus of elasticity (110 GPa), heat resistance capacity (300°C or 572 °F) and strength (137 MPa). Similarly for E-glass, modulus of elasticity (85 GPa), heat resistance capacity (346°C or 656 °F) and thermal conductivity (1.21 W/m.k). Whereas, the material properties of Martensitic stainless steel e.g. modulus of elasticity (175 GPa), heat resistance capacity (750°C or 1400 °F) and strength (400 MPa). There for lower temperature distribution (139.11°C) is found in present study as compared to reported by Thilak *et al.*, 2011 for other material e.g. cast iron and E-glass.



**Fig. 4.1 Temperature distribution for non-vented disc assembly with Martensitic stainless Steel**



**Fig. 4.2 Total Heat flux for non-vented disc assembly with Martensitic stainless Steel**

#### 4.2 Analysis of non-vented disc assembly with Ceramic material

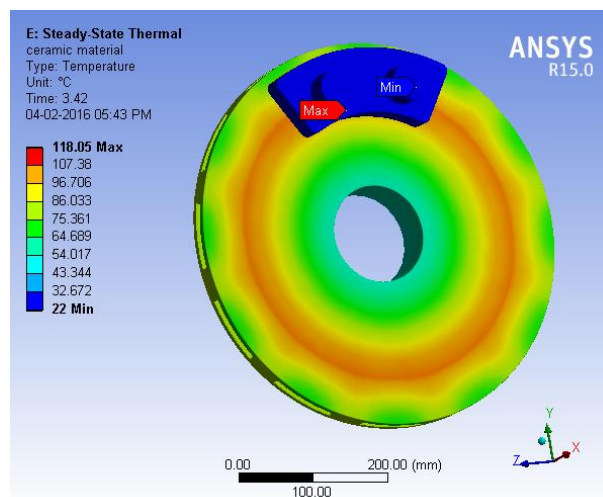
After validation and analysis of non-vented disc assembly 1 with Martensitic stainless steel the analysis of non-vented disc assembly 1 with Ceramic material has been done. The Thilak *et al.*, 2011 and Tiwari *et al.*, 2014 were done the work with cast iron, E-glass (reinforcement material) and structural steel for analysis of disc brake. After the analysis with above material they were suggested for Ceramic material. The Ceramic material is lighter than Martensitic stainless steel and has high fracture toughness, wear resistance capacity, heat resistance capacity (1000 °C to 1600 °C).

##### 4.2.1 Temperature and Total Heat Flux distribution

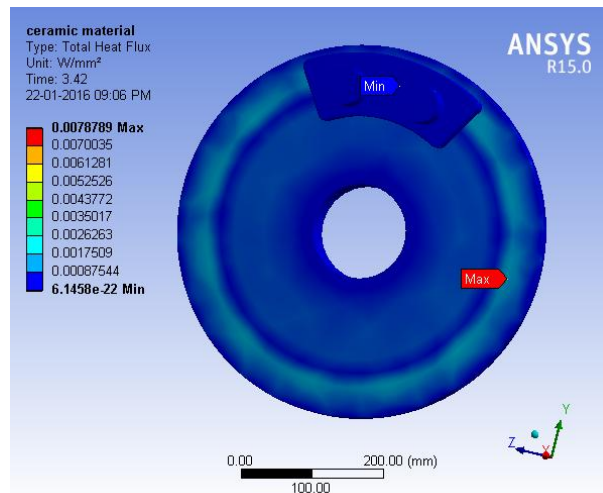
The maximum temperature distribution occurs between the frictional areas of the disc and pad. The temperature of the working surface of the disk is higher than that of the inside of the material of the disc. In this study of Ceramic material, the less temperature distribution as compare to Martensitic stainless steel has been found due to the mechanical and material properties of Ceramic material. After the analysis we found the better results for Ceramic material as compared to Martensitic stainless steel for non-vented condition. The mechanical and material properties of the Martensitic stainless steel have been discussed earlier.

Figure 4.3 and Figure 4.4 display the temperature and total heat flux distribution for non-vented disc brake made of Ceramic material. As it is evident from the Fig. 4.3 and Fig. 4.4, the maximum temperature and heat flux are represented by red colour and the corresponding values are found 118.05 °C and 0.0078789 W/mm<sup>2</sup> respectively. This value is slightly less as compare to Martensitic stainless steel.

Figure 4.3 shows the temperature distribution by the different colours. The blue colour has shows the minimum temperature distribution with the range 22 °C to 32.672 °C while red colour shows the maximum temperature distribution with the range 107.38 °C to 118.05 °C. The Fig. 4.4 shows the minimum heat flux distribution by blue colour with the range from 0.0070035 W/mm<sup>2</sup> to 0.0078789 W/mm<sup>2</sup> respectively. The red colour shows the maximum temperature distribution with the range 107.38 °C to 118.05 °C.



**Fig. 4.3 Temperature distribution for non-vented disc assembly with Ceramic Material**



**Fig. 4.4 Total Heat Flux for non-vented disc assembly with Ceramic Material**  
**V. Comparison of Result**

**Thermal Analysis:** Different outcomes from Thermal analysis is depict in **Table 5**. It gives the result of martensitic stainless steel and Ceramic material. From the result it has been concluded that solid disc brake made of Ceramic material gave less Temperature and Total Heat Flux distribution as compare to Martensitic stainless steel when the load was applied. Therefore, it is suggested to prefer non-vented (solid) type disc brake made of Ceramic material.

**Table 5 Comparison between materials for its best suitability for Non-vented Disc assembly with selected materials**

Material	Temperature Distribution ( $^{\circ}\text{C}$ )	Total Heat Flux ( $\text{W}/\text{mm}^2$ )
Martensitic stainless steel	139.11	0.0096065
Ceramic material	118.05	0.0078789

## VI. Conclusion

After the analysis of disc brake with both material (Martensitic stainless steel and ceramic material), we concluded that the use of Non-vented disc with Ceramic material is the best material for future scope due to its mechanical and material properties e.g. strength, heat resistance and wear resistance capacity.

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