Modelling and Analysis of Disc Brake with Composite Material

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Abstract: ***The purpose of friction brakes is to decelerate a vehicle by transforming the kinetic energy of the vehicle to heat, via friction, and dissipating that heat to the surroundings. Automotive braking systems are normally made of steel or grey cast iron and are then paired with polymer-composite pads. These types of materials are suitable for use in braking systems with moderate loads with a limited temperature capability, where they exhibit a relatively high and stable friction coefficient, a low-wear rate and are quiet during operation. Composite brake discs are lighter, economical, and have excellent high energy friction characteristics. These have twice thermal capability compared to steel, remain unaffected by thermal shocks and mechanical fatigue. These are highly useful in emergency breaking situations. In this paper, carbon ceramic matrix disc brake material and steel material are used for calculating normal force, shear force and braking torque; and also to calculate the braking distance of the disc brake. The standard disc brake model is made using CATIA and the Static Structural analysis to calculate the deformation of the brake model is done using ANSYS. This aids to understand the action of force and friction force on the disc brake's new composite material, and helps to provide evidence so as to why the composite material is better than conventional materials.***

Keywords: Composite matrix material, CATIA, ANSYS, Carbon ceramic disc brake

1. Introduction

Brakes are most important safety parts in the vehicles. Brakes function to slow and stop the rotation of the wheel. To stop the wheel, braking pads are forced mechanically against the rotor disc on both surfaces. The increases in travelling speeds as well as the growing weights of cars have made these improvements essential. An effective braking system is needed to accomplish this task with challenging term where material need to be lighter than before and performance of the brakes must be improved. Today's cars often use a combination of disc brakes and drum brakes. However, the effectiveness of braking system depends on the design itself and also the right selection of material. System that follow with some improvements. In order to understand the behavior of braking system, there are three functions that must be complied for, all the time

a) The braking system must decelerate a vehicle in a controlled and repeatable fashion and when appropriate force is applied, cause the vehicle to stop.
b) The braking should permit the vehicle to maintain a constant speed when traveling downhill.
c) The braking system must hold the vehicle stationary when on the flat or on a gradient.

2. Statement of Problem

Brakes are such a crucial part of the braking system in stopping the vehicle on all moving stages including braking during high speed, sharp cornering, traffic jam and downhill. All of those braking moments give a different value of temperature distribution and thermal stress.

This project concerns itself with the temperature distribution and constraint of the disc brake rotor. Most of the passenger cars today have disc brake rotors that are made of grey cast iron (Mackin, 2002). Grey cast iron is chosen for its relatively high thermal conductivity, high thermal diffusivity and low cost (Mackin, 2002). In this project, the author will investigate on the thermal issues of normal passenger vehicle disc brake rotor. High temperature during braking will cause:

- Brake fade
- Premature wear
- Brake fluid vaporization
- Bearing failure
- Thermal cracks
- Thermally-excited vibration

Due to the application of brakes on the car disc brake rotor, heat generation takes place due to friction and this thermal flux has to be conducted and dispersed across the disk rotor cross section. The condition of braking is very much severe and thus the thermal analysis has to be carried out. The thermal loading as well as structure is axis-symmetric. Hence axis-symmetric analysis can be performed, but in this study, 3-D analysis is performed, which is an exact representation for this type of thermal analysis.

3. Braking System

3.1 Parts of Disc Brake

3.1.1 Brake Calipers

The brake caliper is the assembly which houses the brake pads and pistons. The pistons are usually made of plastic, aluminum or chrome-plated steel.

Calipers are of two types, floating or fixed. A fixed caliper does not move relative to the disc and is thus less tolerant of disc imperfections. It uses one or more pairs of opposing pistons to clamp from each side of the disc, and is more complex and expensive than a floating caliper.

A floating caliper (also called a "sliding caliper") moves with respect to the disc, along a line parallel to the axis of rotation of the disc; a piston on one side of the disc pushes the inner brake pad until it makes contact with the braking surface, then pulls the caliper body with the outer brake pad so pressure is applied to both sides of the disc.

Another type of floating caliper is a swinging caliper. Instead of a pair of horizontal bolts that allow the caliper to move straight in and out respective to the car body, a swinging caliper utilizes a single, vertical pivot bolt located somewhere behind the axle centerline. When the driver presses the brakes, the brake piston pushes on the inside piston and rotates the whole caliper inward, when viewed from the top. Because the swinging caliper's piston angle changes relative to the disc, this design uses wedge-shaped pads that are narrower in the rear on the outside and narrower on the front on the inside.

3.1.2 Brake Pads

Brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Friction can be divided into two parts. They are: adhesive and abrasive.

Depending on the properties of the material of both the pad and the disc and the configuration and the usage, pad and disc wear rates will vary considerably. The properties that determine material wear involve trade-offs between performance and longevity.

The brake pads must usually be replaced regularly (depending on pad material, and driving style), and some are equipped with a mechanism that alerts drivers that replacement is needed, such as a thin piece of soft metal that rubs against the disc when the pads are too thin causing the brakes to squeal, a soft metal tab embedded in the pad material that closes an electric circuit and lights a warning light when the brake pad gets thin, or an electronic sensor.
Generally road-going vehicles have two brake pads per caliper, while up to six are installed on each racing caliper, with varying frictional properties in a staggered pattern for optimum performance.

Early brake pads (and linings) contained asbestos, producing dust which should not be inhaled. Although newer pads can be made of ceramics, Kevlar, and other plastics, inhalation of brake dust should still be avoided regardless of material.

3.1.3 Brake Disc / Disc Brake Rotor

The brake disc is the component of a disc brake against which the brake pads are applied. The material is typically grey iron, a form of cast iron. The design of the disc varies somewhat. Some are simply solid, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces (usually included as part of a casting process). The weight and power of the vehicle determines the need for ventilated discs. The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily-loaded front discs.

Beginning in the 1960s on racing cars, it is now common for high-performance cars, motorcycles and even bicycles, to have brakes with drilled holes or slots. This "cross-drilling" is done for a number of reasons: heat dissipation, surface-water dispersal, brake squeal elimination, mass reduction, or marketing cosmetics. An alleged disadvantage of cross drilling for racing or other severe conditions is that the holes might become a source of stress cracks.

Discs may also be slotted, where shallow channels are machined into the disc to aid in removing dust and gas. Slotting is the preferred method in most racing environments to remove gas and water and to deglaze brake pads. Some discs are both drilled and slotted. Slotted discs are generally not used on standard vehicles because they quickly wear down brake pads; however, this removal of material is beneficial to race vehicles since it keeps the pads soft and avoids vitrification of their surfaces.

As a way of avoiding thermal stress, cracking and warping, the disc is sometimes mounted in a half loose way to the hub with coarse splines. This allows the disc to expand in a controlled symmetrical way and with less unwanted heat transfer to the hub.

On the road, drilled or slotted discs still have a positive effect in wet conditions because the holes or slots prevent a film of water building up between the disc and the pads. Cross-drilled discs may eventually crack at the holes due to metal fatigue. Cross-drilled brakes that are manufactured poorly or subjected to high stresses will crack much sooner and more severely.

4. Material Properties

Table 1: Material Properties of the selected materials

Material Properties	*Silicon Carbide-Reinforced Carbon Composite matrix*	*Stainless Steel*
young's Modulus	250 GPa	193 GPa
Density	1.8 g/cm^3	7750 Kg/m^3
Poisson's Ratio	0.32	0.31
Ultimate Tensile Strength	185 MPa	580 MPa
Bulk Modulus	250 GPa	151 GPa
Shear Modulus	220 GPa	81 GPa
Compressive Strength	3000 MPa	250 a

5. Calculations

5.1 Dimensions of the Disc Plate

Assumptions made for proceeding with the calculations:

Brake disc diameter	:	355 mm
Contact area diameter (Inner)	:	340 mm
Contact area diameter (Outer)	:	190 mm
Pressure applied on the disc during braking	:	P_{max}
Axle diameter	:	85 mm
Hole diameter for bolting	:	20 mm
Disc thickness	:	33 mm
Caliper pad thickness	:	12 mm
Co-efficient of Friction (**μ**)	:	0.5
Vehicle Curb Weight	:	20000 N
Axle weight distribution ratio (γ)	:	0.3
Initial velocity	:	112.5 m/s
Final velocity	:	0 m/s
Percentage of kinetic energy absorbed by the disc	:	0.9

5.2 Force Calculations

Vehicle load on the disc (F_V)	=	(Total load of the vehicle) x (Axle weight ratio)
	=	6000 N
Area of contact (A)	=	(Area of segment from Outer radius) – (Area of segment from Inner radius)
	=	17463.931-1042.13 mm^2
	=	16421.801 mm^2
P_{max}	=	Force on the disc/ Area of the contact
	=	(1.5x20000)/A
	=	1.82632 N/mm^2
Normal load on the disc (F_N)	=	(P_{max}/2) x (Area of the brake pad)
	=	(1.82632/2) x 16421.801
	=	14995.7318 N
Tangential Load (F_T)	=	Normal load x Coefficient of friction
	=	14995.7318 x 0.5
	=	7497.8659 N
Total load on disc while braking (F_S)	=	$F_N + F_T + F_V$
	=	14995.7318+7497.8659+6000
	=	28493.5977 N

Brake torque acting on the disc brake:

Brake torque on the disc	=	(Total load on the disc) x (Radius of the rotor disc)
	=	(28493.5977 N) x 0.1675 N-m
	=	4772.6776 N-m

Braking distance:

Distance covered by the vehicle during braking	=	X m
Work done during braking	=	(Total load on the disc) x (Braking distance)
Kinetic energy released during braking	=	(mass of the vehicle) x (Velocity of the vehicle^2) / 2
Since,		
Work done during braking	=	Kinetic energy released during braking
F_S x (X)	=	$(mv^2) / 2$
28493.5977 N x (X)	=	(20000 x[(π x 355 x 4000)/60]^2) x 0.5
Braking distance (X)	=	31.5 m

6. Model of the Brake Disc

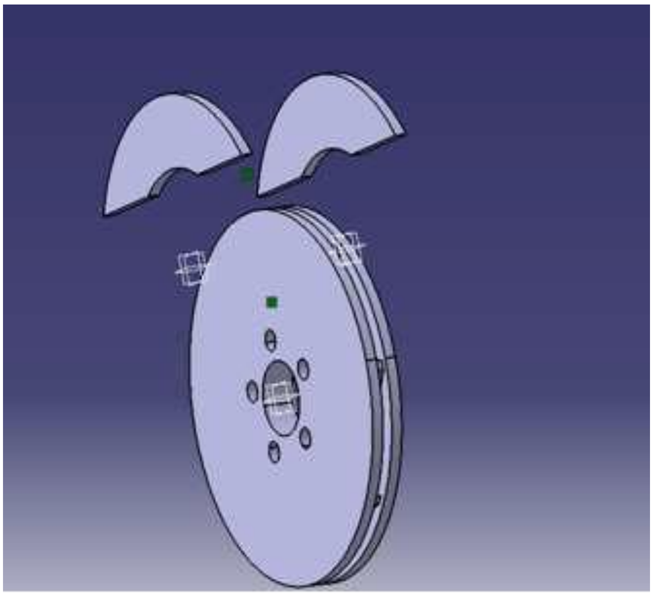

Figure 1: CATIA model of the Rotor Disc Assembly

7. Analysis of Composite Brake Disc

7.1 Static Structural Analysis

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects such as those caused by time varying loads. A static analysis can, however include steady inertia loads (such as gravity and rotational velocity), and time varying loads that can be approximated as static equivalent loads (such as static equivalent wind and seismic loads.

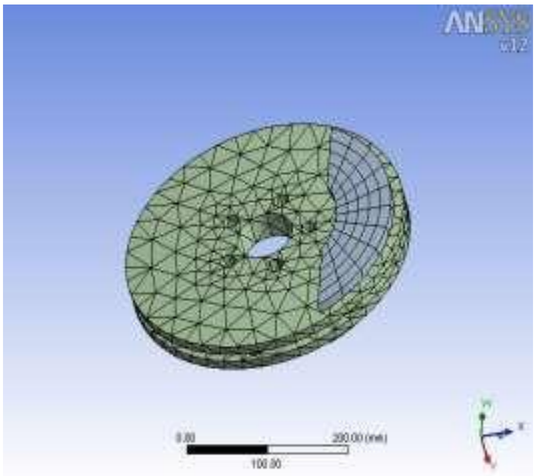

Figure 2: Meshed model of the solid Brake Disc

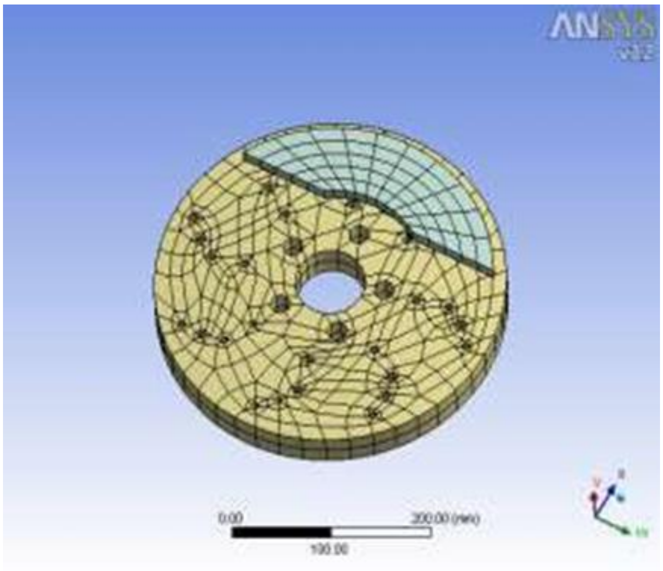

Figure 3: Meshed model f the vented Brake Disc

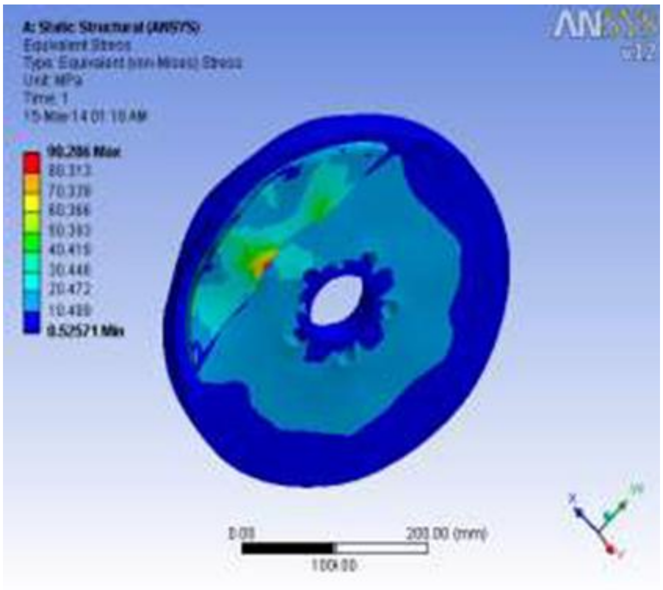

Figure 4: Equivalent Stress (Solid Disc Rotor – Stainless Steel)

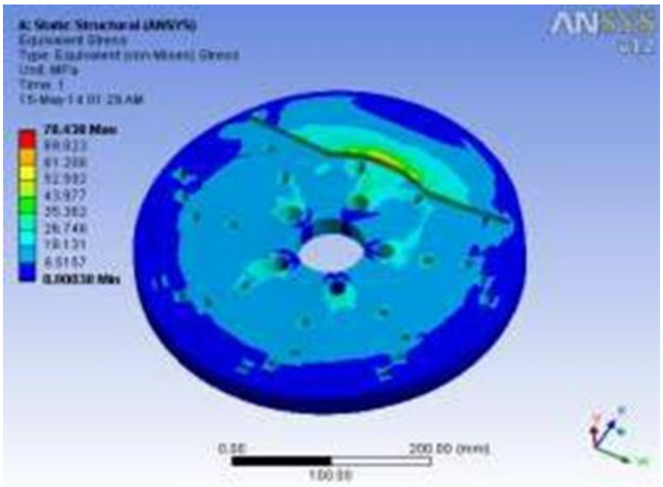

Figure 5: Equivalent Stress (Vented Disc Rotor – Stainless Steel)

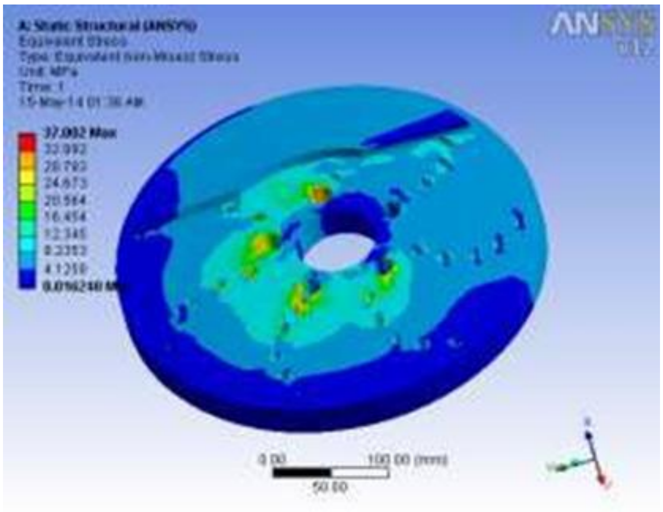

Figure 6: Equivalent Stress (Vented Disc Rotor – Carbon Ceramic composite)

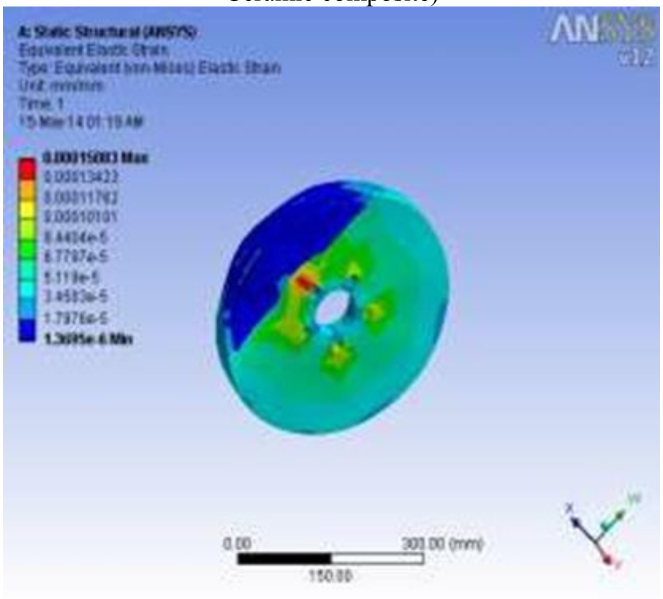

Figure 7: Equivalent Strain (Solid Disc Rotor – Stainless Steel)

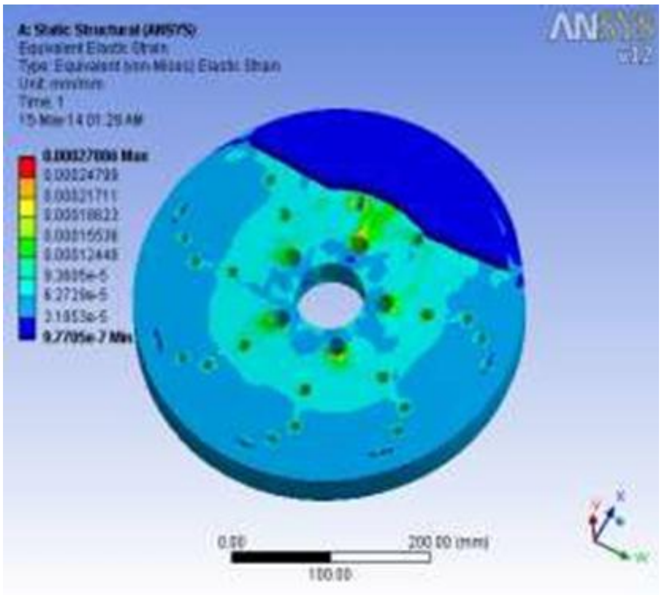

Figure 8: Equivalent Strain (Vented Disc Rotor – Carbon Ceramic Composite)

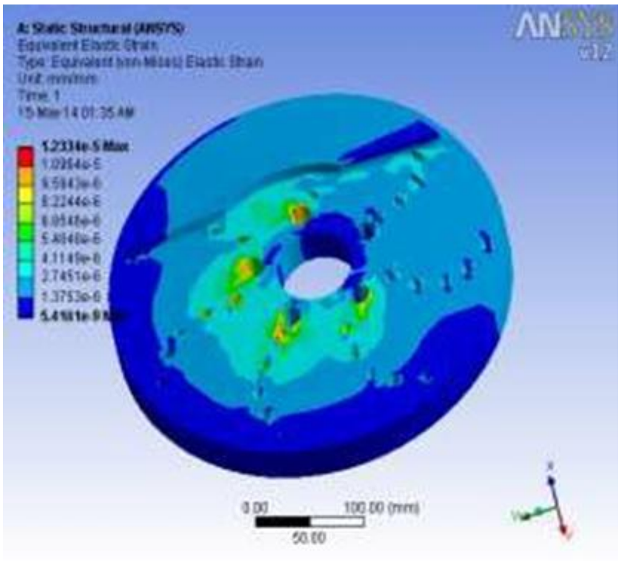

Figure 9: Equivalent Strain (Vented Disc Rotor – Carbon Ceramic Composite)

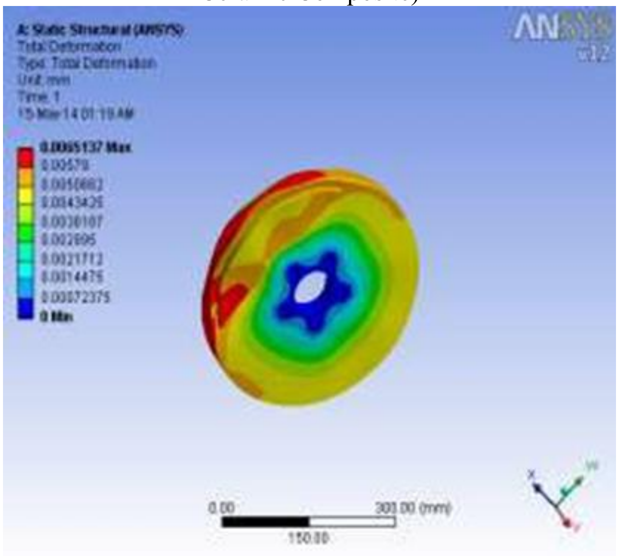

Figure 10: Total Deformation (Solid Disc Rotor – Stainless Steel)

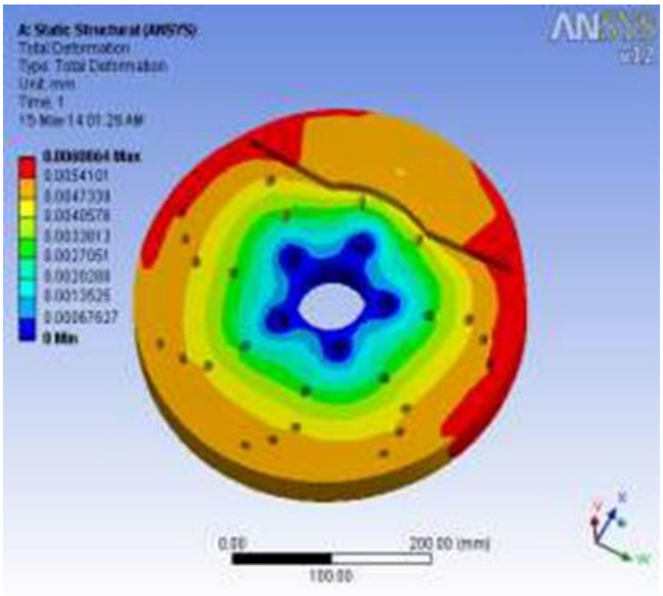

Figure 11: Total Deformation (Vented Disc Rotor – Carbon Ceramic Composite)

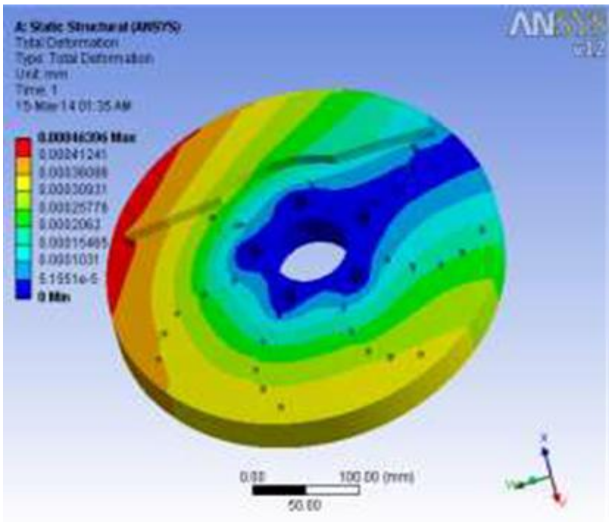

Figure 12: Total Deformation (Vented Disc Rotor – Carbon Ceramic Composite)

8. Conclusion

From the results obtained from ANSYS, we can come to the conclusion that:

- Practical use of C-SiC composite material produces much effective braking compared to steel disc brakes.
- Deformation in steel is much higher than composite, which implies the deformation resistance of the composite structure than the steel material.
- Stress accumulated on the composite is much less, which proves the wear resistance, rigid & stable braking during high speeds.

References

[1] Swapnil R. Abhang, D.P.Bhaskar, "Design and Analysis of Disc Brake", *International Journal of Engineering Trends and Technology (IJETT), Volume 8 Number 4- Feb 2014*

[2] Manjunath T V, Dr Suresh P M, "Structural and Thermal Analysis of rotor disc in Disc Brakes", *IJIRSET ISSN No: 2319- 8753, December 2013*

[3] Grieve, D. G., Barton, D. C., Crolla, D. A., and Buckingham, J. T., "Design of a Light weight automotive brake disc using finite element Techniques", University of Leeds, November 1997

[4] Jancirani, J., Chandrasekaran, S. and Tamilporai, P., "Design and heat transfer Analysis of automotive disc brakes", *ASME Summer heat transfer Conference, Las Vegas, Nevada, July 2003*

[5] Blaz Samec, Iztok Potrc, Matjaz Sram, "low cycle fatigue of modular cast iron used for railway brake disc", *Engineering failure analysis, volume 18 issue Septiembre 6 2011.*

[6] Dr. Kirpal singh, (2011) "Automobile Engineering", Standard Publishers distributors, Vol-1,12th edition.

[7] R.S.Khurmi and J.K. Gupta, "A Textbook of Machine Design"

[8] V. B. Bhandari, "Design of Machine Elements"

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