

Design and Analysis of Automobile Brake Disc by Using Al/SiC MMC

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ABSTRACT: In this project analysis the behaviour of the brake disc with aluminium metal matrix composite material and conventional grey cast iron material in finite element software ANSYS 15.0. Modelling of the disc brake rotor is done using SOLIDWORKS 2010. Finally a comparison is made between conventional grey cast iron and aluminium metal matrix composite materials and the best material for making disc brake have been suggested based on the magnitude of Von misses stresses, temperature distribution and deformation from the analysis result.

KEYWORDS: Disc brakes, temperature distribution, MMC, AMC, Silicon carbide, Stir casting, composite materials.

I. INTRODUCTION

Disc brakes are an important component of our automobiles. They are employed to halt the vehicle or to slow the vehicle to a required velocity from a given initial velocity. To stop the wheel, braking pads are forced mechanically against the rotor or disc on both surfaces. They are compulsory for the safe operation of all vehicles. In short, brakes transform the kinetic energy of the car into heat energy, thus slowing its speed. Brake fade is the reduction in stopping power that can occur after repeated or sustained application of brakes, especially in high load or high speed conditions. Brake fade can be a factor in any Vehicle that utilizes a friction braking system including automobiles, trucks, motorcycles, airplanes, and even bicycles. Brake fade is caused by a build-up of heat in the braking surfaces and the subsequent changes and reactions in the brake system components and can be experienced with both drum brakes and disk brakes.

Loss of stopping power, or fade, can be caused by friction fade, mechanical fade, or fluid fade. Brake fade can be significantly reduced by appropriate equipment and materials design and selection, as well as good cooling. It is more prevalent in drum brakes due to their configuration.

Disc brakes are much more resistant to brake fade because the heat can be vented away from the rotor and pads more easily, and became a standard feature in front brakes for most vehicles.

❖ Classification of brakes

Classification of brakes (based on transformation of energy):

- Hydraulic brakes.
- Electric brakes.
- Mechanical brakes

❖ Mechanical Brake:

Mechanical brakes are assemblies consisting of mechanical elements for the slowing or stopping of rotating material. They use levers or various leverage to transmit force from applied place to brake. Mechanical brakes according to the direction of acting force may be sub divided into the following two groups:

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- Radial brakes.
- Axial brakes.
- **Radial Brake:** In these brakes the force acting on the brake drum is in radial direction. The radial brake may be subdivided into external brakes and internal brakes.
- **Axial Brake:** In these brakes the force acting on the brake drum is only in the axial direction, e.g., Disc brakes, Cone brakes.
- ✧ **Electric Brake**

Electric brakes are assemblies of electrical elements for the slowing or stopping of rotating objects. Electrical power is required to activate the brake.

✧ Hydraulic Brake

Hydraulic brakes use a fluid to transfer pressure and actuate the braking mechanism.

- Disc Brake:

A disc brake consists of a cast iron disc bolted to the wheel hub and a stationary housing called caliper. The caliper is connected to some stationary part of the vehicle, like the axle casing or the stub axle and is cast in two parts, each part containing a piston. In between each piston and the disc, there is a friction pad held in position by retaining pins, spring plates, etc., passages are drilled in the caliper for the fluid to enter or leave each housing. These passages are also connected to another one for bleeding. Each cylinder contains rubber-sealing ring between the cylinder and piston.

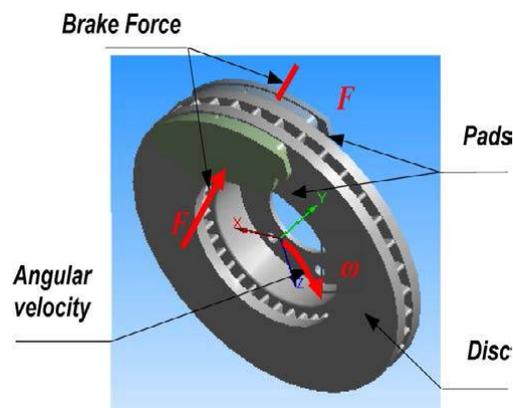


Figure 1.1 Schematic Diagram of Disc Brake

★ Disc Brake Components

- Caliper: The brake calipers have a two brake pads and wheel cylinder. There are two types of disc calipers where further classified as floating and fixed caliper shows a type of floating caliper. This type of brake uses only a single piston to squeeze the brake pad against the rotor (BOSCH, 1992). The reactive force shifts the caliper housing and presses opposite side of braking pad against rotor. Referring to Figure the brake fluid pushes the piston when the brake is applied to the left of the piston and immediately pushes the inner pads and presses it against the rotor disc, the sliding calliper housing reacts by shifting towards right pushing the left pad against the disc. Floating Caliper Design (Source: BOSCH Automobile Handbook, 1992) other type of disc calipers is a fixed caliper shows a type of fixed caliper. In these types of brakes, the caliper body is fixed

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and uses two or more pistons on each side of the rotor. The pistons are located in each half section of the fixed caliper.

- Brake pad: The pad is mostly made on the non metallic materials eg. Ceramic materials. Brake pads consist of steel carrier which the pad are bonded to the steel carrier. According to (Gerschler, 1980), organically bonded pads consist of metallic, ceramic or organic friction materials in a bonded mass such as rubber or synthetic resin. The bonded friction materials can withstand temperatures up to 750°C, with short term peaks-up to 950°C where the friction coefficient is between 0.25 and 0.5. There is an advantage of brake pads, where most of them are poor to thermal conductivity which protects the hydraulic actuating elements from overheating.
- Piston: It is used to push the brake pad by the flow of brake fluid.
- Rotor or disc: It provides a smooth surface against which to face the brake pads, to slow or stop the vehicle. The heat generated on the surfaces of disc brake rotor when brake applied. Materials of disc brake rotor usually are made from cast iron, spheroidal- graphite cast iron or cast steel. It is chosen as a rotor material due to low cost of material and performs high thermal resistance. This type of material normally suit to normal passenger vehicle but not for high performance car. Once brake pads contacts to rotating rotor, there will be huge amount of heat generated to stop or slow down the vehicle. The rotor temperature can exceed 350°C for normal cars and 1500°C for race cars (Halderman, 1992).
- Master cylinder: Its carries the brake fluid we apply the brake to supply to wheel cylinder.

II. MATERIAL SELECTION

❖ General Material Requirements

Disc brake systems generate braking force by clamping brake pads onto a rotor that is mounted to the hub. The high mechanical advantage of hydraulic and mechanical disc brakes allows a small lever input force at the handlebar to be converted into a large clamp force at the wheel. This large clamp force pinches the rotor with friction material pads and generates brake power. The higher the coefficient of friction for the pad, the more brake power will be generated. Coefficient of friction can vary depending on the type of material used for the brake rotor. Typically service brakes are concerned with the coefficient of friction measured while the vehicle is moving.

All modern disk brakes systems rely on brake pads pressing on both sides of a brake rotor to increase the rolling resistance and slow the car down. The amount of frictional force is found by multiply the force pushing the pad into the rotor by the coefficient of friction of the pad. So, the force slowing the brake disc or rotor is

$$F_{\text{ROTOR}} = 2C_f \text{ pad } F_{\text{pad}}$$

The braking system is a vital safety component of ground based transportation systems hence the structural materials used in brakes should have possess some combination of properties such as good compressive strength, higher friction coefficient, wear resistant, light weight, good thermal capacity and economically variable.

❖ Reason for Choosing Al/SiC

Particulate reinforced aluminium MMC's are promising candidate for automotive applications since they offer high specific stiffness and strength, good wear resistance and suitable thermal properties; furthermore, they are readily available at reasonable prices and can be processed using conventional technologies.

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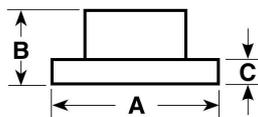
❖ Properties of Materials

PROPERTIES	GREY CAST IRON	Al/5%SiC	Al/10%SiC	Al/12.5%SiC
Coefficient of friction (μ)	0.41	0.3	0.44	0.51
Density Kg/m ³	7200	2730	2760	2775
Specific heat J/ (kg ° C)	460	910	830	790
Thermal conductivity W/m ° C	52	128	136	120
Coefficient of thermal expansion /°C	1.37E-05	1.81E-05	1.56E-05	1.47E-05
Elastic modulus N/mm ²	125000	86030	99660	106475
Poisson's ratio	0.25	0.25	0.258	0.262
Convection film coefficient W/mm ² °C	0.001	0.001	0.001	0.001

III. THEORITICAL CALCULATION

❖ Dimensions of the Disc Plate

The Specification of HUYNDAI i20 car [Front Disc Brake Rotor]:



A = DIAMETER D = MIN. THICKNESS
B = ORIGINAL HEIGHT E = CENTRE HOLE DIA.
C = ORIGINAL THICKNESS F = NO. OF BOLT HOLES

Figure 3.1 Specification of Disc Rotor

Rotor disc outer diameter	= 256 mm	
Rotor disc original height	= 47 mm	
Rotor disc original thickness	= 22 mm	
Rotor disc minimum thickness (Replacement)		= 20 mm
Centre hole (bore diameter)	= 62 mm	
No of bolt holes (100 PCD)	= 4	
Rotor disc outer radius (contact)	= 125 mm	
Rotor disc inner radius (contact)	= 85 mm	
Rotor disc original half thickness	= 11 mm	
Contact Area	= 22.22%	
Volume of disc (V)	= 0.000708 m ³	

❖ Dimensions of the vehicle:

Mass of the vehicle unladen	= 1250 Kg	
Mass of the vehicle laden(m)	= 2000 Kg	
Axle weight distribution ratio	= 0.3	
Velocity at begin of braking (v)	= 30 m/s	
Deceleration -const (a)	= 0.6g = 5.9 m/s ²	
Deceleration downgrade (10 deg) = 0.6+sin (10)		= 0.77g m/s ²
Deceleration uphill (10 deg) = 0.6-sin (10)		= 0.43g m/s ²

❖ Calculation:

Braking time - (t) = v/a sec

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$$= 30/5.9 = 5.10 \text{ sec}$$

$$\text{Braking energy (E)} - (\frac{1}{2} \times m \times v^2) + (\frac{1}{2} \times I \times \omega^2)$$

$$= \frac{1}{2} \times m \times (1 + I / (mR^2)) \times v^2 = (k \times m \times v^2) / 2$$

$$\text{Correction factor for passenger car in low gear (k)} = 1.25 \text{ to } 1.6 = 1.4$$

$$\text{Braking energy (E)} = (1.4 \times 2000 \times 30^2) / 2$$

$$= 1260000 \text{ Nm}$$

$$\text{Braking power (P)} = \text{Braking energy} / \text{Time} = 1260000 / 5.10$$

$$= 247.21 \text{ kW}$$

$$\text{Braking Torque (T)} - \text{Total force} \times \text{Radius} = F \times (r_1 + r_2) / 2$$

$$\text{Uniform wear} - R = (r_1 + r_2) / 2$$

$$\text{Pressure applied on the disc during braking (Max)} = 1.5 \times m \times g / \text{contact Area}$$

$$= 1.5 \times 19620 / ((\pi \times 0.125^2 - \pi \times 0.085^2) \times 0.2222)$$

$$= 5.02 \text{ N/mm}^2$$

$$\text{Tangential force (Ft)} = \text{coefficient of friction} \times \text{Normal force (Fn)}$$

$$\text{Normal force (Fn)} = (\text{Max pressure} / 2) \times \text{Area of pad} = (5.02 / 2) \times ((\pi \times 0.125^2 - \pi \times 0.085^2) \times 0.2222)$$

$$= 14715 \text{ N}$$

$$\text{Tangential force (Ft)} = \mu \times \text{Fn}$$

$$= 0.41 \times 14715$$

$$= 6033.15 \text{ N}$$

$$\text{Vehicle load on disc (Fv)} = \text{Weight of vehicle} \times \text{Axle weight distribution ratio}$$

$$= 19620 \times 0.3$$

$$= 5886 \text{ N}$$

$$\text{Total force (F)} = \text{Fn} + \text{Ft} + \text{Fv}$$

$$= 14715 + 6033.15 + 5886$$

$$= 26634.15 \text{ N}$$

$$\text{Braking Torque (T)} = 26634.15 \times (0.125 + 0.085) / 2$$

$$= 2796.59 \text{ N-m}$$

$$\text{Work done} = \text{braking energy (E)} = \text{Heat generate (Hg)} = F \times \text{braking distance}$$

$$\text{Braking distance (x)} = E / F$$

$$= 1260000 / 26634.15$$

$$= 47.31 \text{ m}$$

$$\text{Rise in temperature } (\Delta T) = \text{Braking energy} / (\text{density} \times \text{volume} \times \text{Sp.heat})$$

$$= 1260000 / (7200 \times 0.000708 \times 460) = 537 \text{ } ^\circ\text{C}$$

$$\text{Heat flux} = \text{Heat generated (Hg)} / (\text{surface area} \times \text{braking time})$$

$$= 1260000 / ((\pi \times 0.125^2 - \pi \times 0.085^2) \times 5.1) = 9367.86 \text{ KW/m}^2$$

$$\text{Heat penetration time} = (\text{Half thick disc})^2 / (5 \times \text{thermal diffusivity})$$

$$\text{Thermal diffusivity} = \text{Thermal conductivity} / (\text{density} \times \text{Sp.heat})$$

$$= 52 / (7200 \times 460)$$

$$= 1.57 \times 10^{-5} \text{ m}^2/\text{sec}$$

$$= 15.7 \text{ mm}^2/\text{sec}$$

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Heat penetration time = $(11) \sqrt{2 / (5 \times 15.7)}$ = 1.54 sec

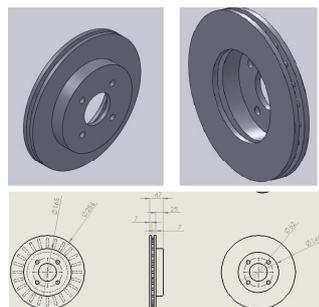
❖ Summary Of Calculation: - Brake Disc

Table 3.1

		GREY CAST IRON	Al / 5% SiC	Al / 10% SiC	Al / 12.5% SiC
1	Braking time - to stop (t) - sec	5.10	5.10	5.10	5.10
2	Braking energy (E) - Nm	1260000	1260000	1260000	1260000
3	Braking power (P) - kW	247.2	247.2	247.2	247.2
4	Pressure applied on the disc (Max) - N/mm ²	5.02	5.02	5.02	5.02
5	Normal force (Fn) - N	14715	14715	14715	14715
6	Tangential force (Ft) - N	6033.15	4414.5	6474.60	7504.65
7	Vehicle load on disc (Fv) - N	5886	5886	5886	5886
8	Total force (F) - N	26634.1	25015.5	27075.6	28105.6
9	Braking Torque (T) - Nm	2796.59	2626.63	2842.94	2951.09
10	Braking distance (x) - m	47.31	50.37	46.54	44.83
11	Rise in temperature (ΔT) - °C	537	716	777	812
12	Heat flux – KW/m ²	9367.86	9367.86	9367.86	9367.86
13	Thermal diffusivity – mm ² /sec	15.7	51.52	59.37	54.74
14	Heat penetration time - sec	1.54	0.47	0.41	0.44

IV. MODELING

The modeling of the disc brake is done using solid works. Dimensions were taken from Australian brake disc dimension book.



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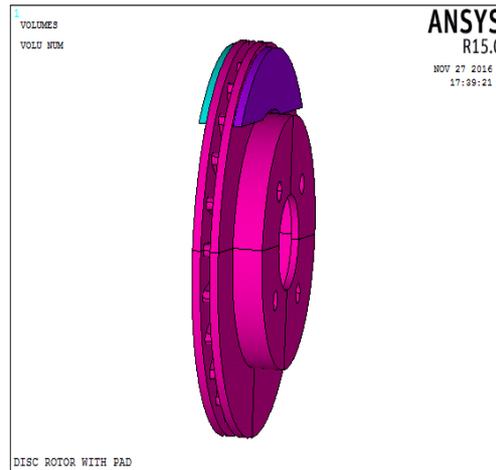


Figure 4.1 Brake Disc model

V. ANALYSIS

❖ . Meshing Model

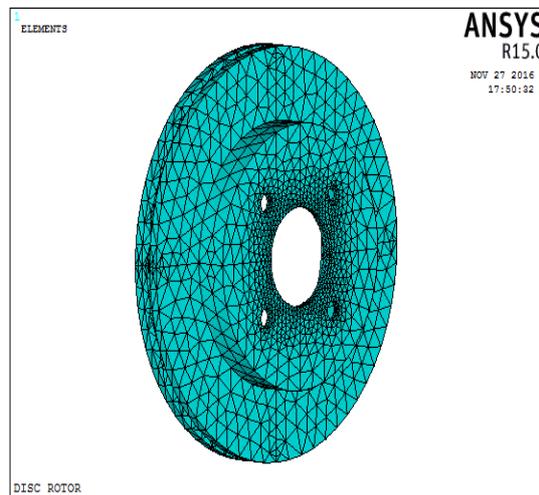


Figure 5.1 Brake Disc meshing model

Meshed Model:

- Solid 226 is used as an element.
- Free mesh had been done.
- Total numbers of elements are 68286.
- Total numbers of nodes are 124193.

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❖ Thermal analysis:

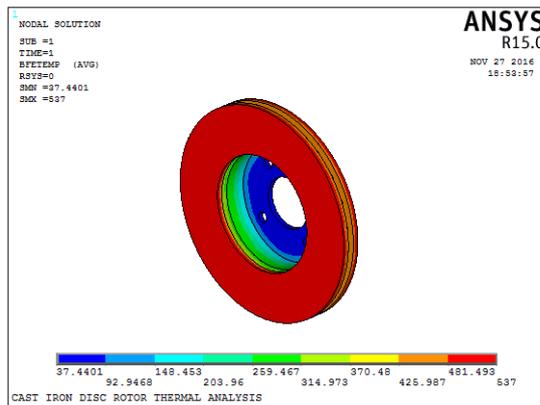


Figure 5.2: Body Temperatures Of Cast Iron Brake Disc

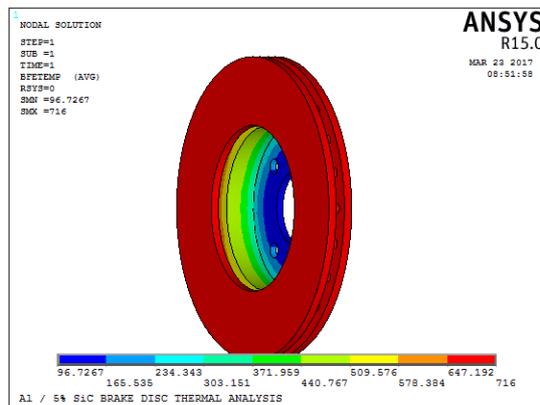


Figure 5.3: Body Temperatures Of Al / 5% SiC Brake Disc

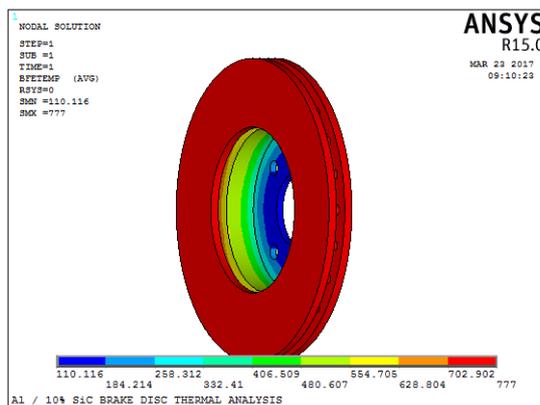


Figure 5.4: Body Temperatures Of Al / 10% SiC Brake Disc

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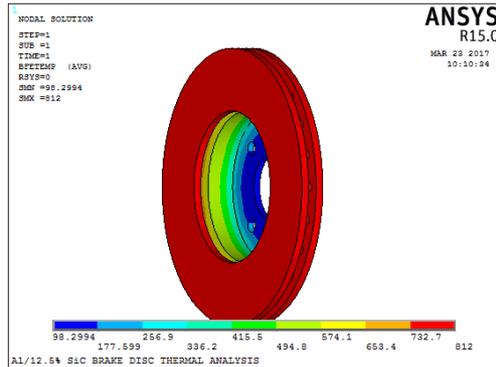


Figure 5.5: Body Temperatures Of Al / 12.5% SiC Brake Disc

❖ Thermal - Structural Analysis

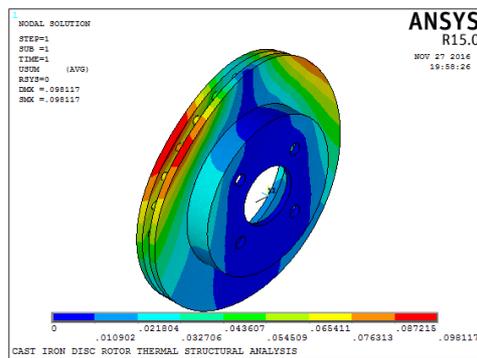


Figure 5.6: Thermal-Structural Displacement Of Cast Iron Brake Disc

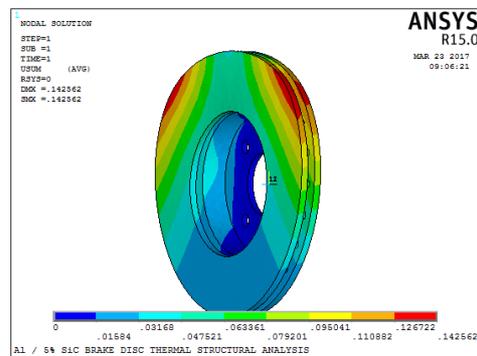


Figure 5.7: Thermal-Structural Displacement Of Al/5% SiC Brake Disc

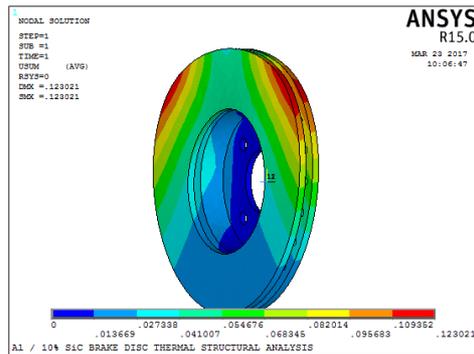


Figure 5.8: Thermal-Structural Displacement Of Al/10% SiC Brake Disc

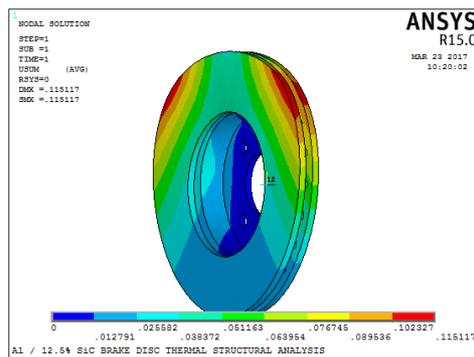


Figure 5.9: Thermal-Structural Displacement Of Al/12.5% SiC Brake Disc

❖ **Summary Of Analysis: - Brake Disc**

Table 5.1

		GREY CAST IRON	Al / 5% SiC	Al / 10% SiC	Al / 12.5% SiC
1	Body Temperatures (°C)	37.44 -537	96.72 -716	110.11 -777	98.29 -812
2	Thermal Flux – KW/mm ²	8.48 -6258.83	63.76 -13445.8	75.97 -15064.6	65.83 -14884.7
3	Thermal Gradient - ° C/mm	0.16 -120.36	0.49 -105.12	0.55 -110.76	0.54 -124.03
4	Structural Displacement–mm	0.00 - 0.99	0.00 - 0.14	0.00 - 0.12	0.00 - 0.11
5	Structural Von Mises Stress - N/mm ²	0.12 - 181.87	0.12 - 181.87	0.12 – 180.96	0.11 - 180.50
6	Thermal- Structural Displacement – mm	0.00 - 0.09	0.00 - 0.14	0.00 - 0.12	0.00 - 0.11
7	Thermal- Structural Von Mises Stress - N/mm ²	0.13 - 179.73	0.13 - 179.73	0.12 - 178.82	0.12 - 178.37

VI. CONCLUSION

Comparison of stress distribution, displacement and temperature distribution for conventional and proposed material indicates that Al/SiC MMC with 10% SiC satisfies the requirement for disc brake application. It is concluded that

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Al/SiC MMC with 10% SiC can be used in automotive to replace the conventional material for improved vehicle performance.

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